CITY ROADS

AND

PAVEMENTS

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OSWEGO, NEW YORK, 1902.

Looking up West Oneida Street from West First Street.

Brick on concrete laid in 1898 between Federal and Municipal Buildings on Oneida Street. Sheet asphalt (Trinidad Lake) laid in July, 1897 on First Street, in foreground, and in August, 1898, on Oneida Street, from Second Street to Fifth Street, in distance. Also on three miles of adjoining streets, part of which was laid in 1895. **All in perfect condition in 1902 with no repairs.**

CITY

ROADS AND PAVEMENTS

SUITED TO

CITIES OF MODERATE SIZE.

Second Edition, Revised and Enlarged.

BY

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PREFACE TO SECOND EDITION.

The local features of the first edition, having served their purpose, have been omitted, and modifications have been made to show the present applications of general methods, some of which have changed since 1894. The most marked change during the past eight years has been in the increased use of crushed stone for roadways of macadam and of telford construction, on the improved streets of villages and cities. A notable instance is that of the city of Greater New York, which contains outside its parks eight hundred miles of crushed stone roads built since 1894.

This general increase has resulted in part from the work begun in 1893 by the State of New Jersey, followed in 1894 by Massachusetts, in 1895 by Connecticut and in 1898 by New York. The examples given by the governments of these States in building highways by State aid and outside corporate limits, have led to the building by the municipalities of similar roads within many cities and villages, which have thus wisely profited by the experienced methods of State officials.

The results have been an increasing extent of the best kinds of roads of broken stone, and a growing knowledge of the methods and machines by which alone can such roads be built and maintained. These are here described under the heading "Broken Stone Roads," without however differing essentially from the descriptions given in the first edition.

The grade of a city street is usually a fixed condition and not a theory, and it is often difficult to decide which is the best pavement for a fixed steep grade in a given climate, or how steep a grade will give good results with a given pavement. Tables of actual instances are given in order that engineers may know where to find conditions similar to their own, and where they may examine certain pavements in actual use. To watch the traffic using a steep paved slope or to examine its condition during a sharp shower or after a heavy rain, will suggest points as to the proper grade and crown which will be worth any amount of theorizing as to maximum grades.

The sections entitled respectively "Concrete Base," "Block Stone," "Wood," "Vitrified Brick," "Asphalt," "Bituminous macadam' and "Broken Stone," are made to accord with the latest records of methods and costs, using illustrations and tables for brevity. These records have been obtained from personal practice and investigation and from the publications and discussions of the several Societies of Civil Engineers, from the reports of the officials of States and Cities, and from the columns of Engineering News, The Engineering Record, Municipal Journal and Engineer, The Engineering Magazine and Municipal Engineering, and also directly from many civil engineers in addition to those whose names are mentioned. The uniform courtesy shown by civil engineers, both in the United States and abroad, in cordially meeting inquiries regarding their works, methods and results, and in freely giving all desired information, is a marked and peculiar characteristic of the Profession.

These statements of facts and opinions are meant for those who wish to profit by the varied experiences of practical road makers.

Wm. P. J.

Oswego, New York,
May 1, 1902.

CITY ROADS AND PAVEMENTS

SUITED TO CITIES OF MODERATE SIZE.

The extent of street-surface in the cities having a population of fifty thousand or less is usually such that only a portion can be paved or improved at any one time, and it is therefore necessary to carefully study the local conditions existing in any given city in order to determine which of the various kinds of pavement are best suited to the existing conditions of slope and of traffic and of treasury, and to the local supplies of proper materials.

REDUCTION OF SURFACE TO BE PAVED.

In cities which have always had dirt roads, the actual width of roadway is usually much greater than is needed for the traffic, and the subject should first be studied with a view to reducing the area to be paved by widening the bermes and the sidewalks on each side of the street, and thus narrowing the roadway to a width no greater than the traffic demands. Many cities have 42 feet to 45 feet width of dirt roadway on residence streets where 26 feet and 32 feet would be an ample width between the curbs of the same streets when they are paved; 32 feet is the width most often used. The beauty of the streets will be much improved by such change and by forming on each side of the street a wider grassy berme outside of a row of trees, and this change will also give room for wider sidewalks, which in many cases are much needed. These wider bermes can usually be formed from the worn earth and sand which must be scraped from the surface of the existing old roadways before attempting to form new ones.

DRAINAGE OF ROADWAY.

Having determined the proper widths of roadway of the various streets, their grades should be most closely studied in order to get the best results with the least change of existing grades; it should be considered that the proposed pavements with their curbs, crossings, manholes and catch-basins will be, or should be, permanent structures and they should be located carefully.

Before paving any street, there should be in place a complete system of sewers and of pipes for water and for gas with service-branches to every lot on both sides of the street, and with manholes to give access to the sewers, and with catch-basins so arranged as to take the storm-waters without blocking the sewers with street-waste and silt, which can readily be prevented from entering the sewers by the use of recent improvements in catch-basins. In designing these sewers, and in considering whether existing sewers are sufficient, it must be remembered that the proposed pavements will bring the storm-water into the sewers more quickly and that larger capacity will be needed to carry the increased flow.

Careful consideration should also be given in order to decide whether the local conditions make it best to provide subways for electric wires.

The thorough drainage of such streets as have been naturally muddy in spring and in fall, must be provided for before any method of paving or surfacing is considered. The natural earth is the real roadbed which does the work, and it can only support the pavement — of whatsoever kind it may be — by being kept dry.

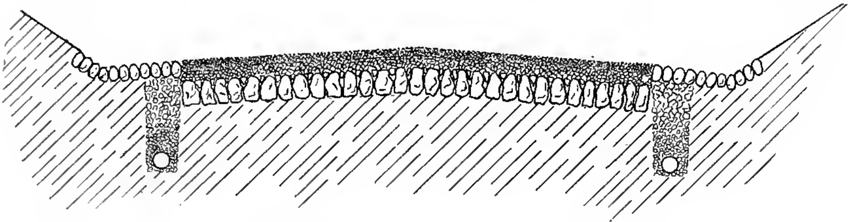
In most of the cities, a portion of the streets have good grades and will drain naturally if rightly formed; and it is the streets running at right angles to these which will be most difficult to drain, especially if they are on a hillside having springs in the subsoil, which must then have sub-drainage by tile drains before any form of surface or of pavement will be of permanent value or effect.

There are many such streets on which rain water now stands until it evaporates. On the ordinary street in northern cities, the direct rainfall between fence-lines per mile, is equal to 30,000 tons or 8 million gallons of water every year, and there are many streets where this water has been left to evaporate or to soak into the ground.

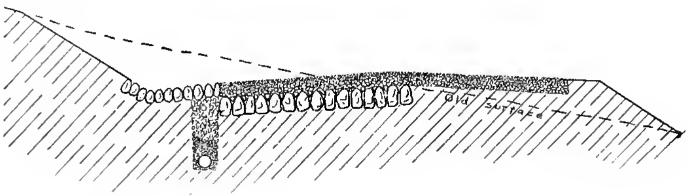
SUB-DRAINS.

Any such roadbed, where, from any cause, water naturally stands and forms mud, must be thoroughly sub-drained. To put broken stone, or gravel, or any valuable material of any kind upon a bed of earth and ashes which rain will convert to mud, is to throw away both money and material.

The sub-drains should consist of lines of two inch to four inch porous tile, or four inch to six inch vitri-



fied tile laid with open joints; one line on each side of a level road which receives drainage from both sides, or one line only on a hill-side road, this being put

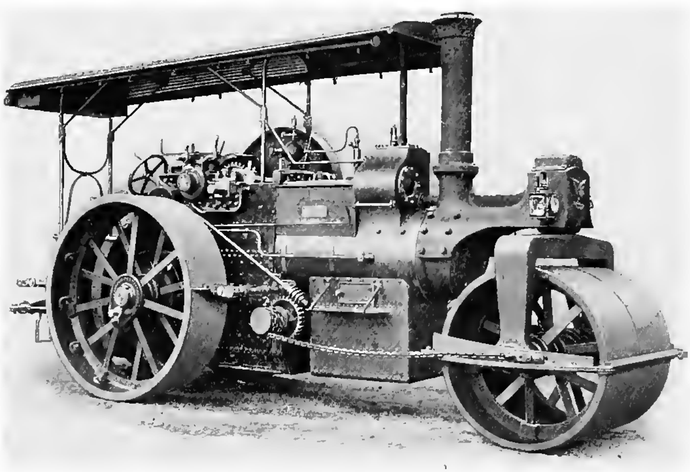


on its up-hill side to intercept ground-water from the higher ground. These tiles should be placed on an accurate grade, a foot or more below the bottom of the gutter, next to the curbs, away from tree-roots and below frost, in order to lead the ground-water to the catch-basins or road-culverts, from which it will run to the sewers or outlets with the surface-water from the pavement.

The provision of this sub-drainage should be the first move toward making any permanent roadway on a flat street.

ROLLING THE EARTH ROADBED.

For any method of road-making or of paving which may be adopted, a steam roller of about ten to twelve tons weight is requisite in order to compact the earth roadbed so that it will sustain the wheels which will pass over it. As well try to make the bricks of old Egypt without straw as to try to make the roads of to-day without a heavy steam roller. Every fully equipped road-builder has one or more. There are few cities which have not made some effective efforts to have good roads, and those which have done so know from experience that no good results can be expected until the proper tools are used. For any system of pavements or of roads, a steam roller is the thing first needed, and no contractor's bid should be considered unless he agrees to provide and use a steam roller of at least ten tons weight so proportioned as to give not less than 500 pounds pressure per lineal inch of face of the roller-wheels.



The undulations and hollows which may be seen in the surface of many existing pavements are the direct results of the lack of a proper roller which would first have disclosed the presence of the soft places in the earth roadbed, and then would have packed the grading-material into them, so that the finished pavement would have had a solid and permanent foundation and a regular surface.

GOOD EFFECT OF ROLLER ON DIRT ROADS.

Especially valuable would such a roller be for cities having great extent of dirt roads, which could be formed by use of the wheeled scraper and then rolled to a smooth, hard surface, furnishing fine roadways during the summer months until the fall rains make them muddy. By rolling the roads as they freeze, towns can make their earth streets smooth for the whole winter and so that a few inches of snow will give good sleighing.

Nearly a mile per day of temporary, summer roadway can be made at small cost by a scraper, sprinkler, and steam roller working together.

The sprinkler should be selected to have six-inch tires with rear axle two inches longer on each end than the front axle; it should be built without a reach so that it can be turned without digging holes in the roadway, and should have a sprinkler which is under the perfect control of the driver.

The roller should be selected to be of not more than ten or twelve tons actual weight when loaded, so that it can cross ordinary bridges safely and can roll streets without crushing buried pipes. The roller should be tested to see that it can climb ten per cent grades when they are covered with loose stone, and also that it can hold its steam-pressure during continuous operation, and it should also have a record for durability under rough usage.

WIDE TIRES ON WHEELS.

To supplement the good effect of a roller on the dirt roads, which are now cut by narrow tires, the use of wide tires on heavy wagons should be required. The following is a practicable way of initiating such a rule:

Let the Board of Public Works of any city order that no wagon will be employed upon city work unless it has four-inch tires on its wheels, with the front axle eight inches shorter than the rear axle. This will make each wagon equal to two eight-inch rollers.

Let the same order be applied to ice-wagons and to public carters, as a condition of issuing a license. A future date could be published at which all heavy wagons doing business in the city, including farmers' wagons from the surrounding country, shall have such wheels. This publication will stop the sale of narrow-tired wagons, which will gradually be displaced by those with wide tires, when the roadways of the vicinity as well as of the city itself, will no longer be so deeply cut and furrowed as now by the pressure of traffic.

PRESSURE OF TRAFFIC.

It is only necessary to consider the great pressure which ordinary traffic will put upon the roadbed in order to realize that no pavement can keep its form and its regular surface unless the earth roadbed, on which all the pressure finally comes, has been perfectly compacted before the pavement is laid over it; for the pavement, of whatever material it may be, is merely a

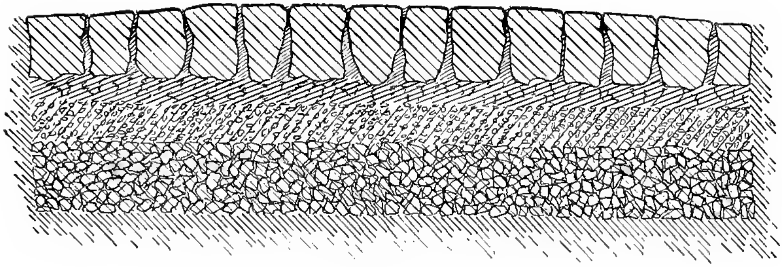
more or less rigid surface which receives the pressure of traffic and distributes it to the supporting earth. For instance, the ordinary coal wagon, weighing 1,200 pounds, draws two tons of coal and has tires two inches wide. As the wagon stands on the pavement, the bearing surface does not exceed a length of one and one-half inches on each wheel; the four wheels thus standing upon a total surface of twelve square inches, with a total pressure of 5,200 pounds, or 433 pounds per square inch, and this is applied with a rolling pressure which is most destructive.

COMPARISON WITH PRESSURE OF STRUCTURES.

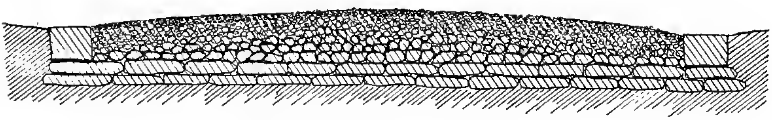
The degree of pressure which this puts upon any pavement will be best appreciated by comparing it with the pressures per square inch upon the clay, sand, or earth underlying the foundations of some well-known great structures.

The Cleveland viaduct	14 to 23 lbs.	per sq.	in.
The 1894 London tower bridge	21	"	"
The sixteen-story office buildings of Chicago	21	"	"
The Memphis bridge piers	22	"	"
The Albany capitol	28	"	"
The Brooklyn bridge anchorage	56	"	"

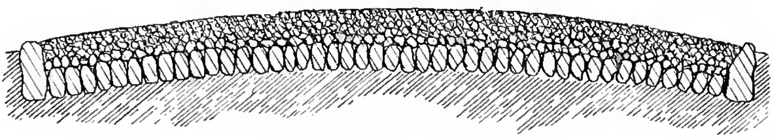
The earth supporting these structures is, of course, compressed to the greatest degree in its natural formation, but the average pressure of these structures is less than one-sixteenth of the pressure concentrated on an ordinary wagon wheel.



Ancient Roman Road.



Early Eighteenth Century Road.



Late Eighteenth Century Road.

Modern Macadam Road.

RELATIVE THICKNESS OF ANCIENT AND MODERN ROADS.

ANCIENT PAVEMENTS.

Paved highways were built by the Romans through Europe and throughout the Empire two thousand to twenty-two hundred years ago, and portions of these pavements still endure. Many of them have been examined to learn whether the details of their construction included features which are now worthy of imitation.

It is found that the locations of these roads were usually made in the simplest manner, ignoring natural obstacles and directing the course by straight lines toward prominent landmarks. Upon the lines thus defined, the width of the proposed roadway was then marked by two parallel furrows which were eight feet to twenty feet apart according to the importance of the highway. Between these furrows all unstable materials were excavated, usually to a depth of about three feet, and in this undrained trench the road materials were placed in more or less regular layers.

The *statumen*, or base, was formed of one course, or sometimes of two courses, of large flat stones laid in lime mortar, and was usually about fifteen inches thick. Upon this was formed a 9-inch course of small fragments of stone which were embedded in sufficient lime-mortar to fill their voids, and which thus bound together the tops of the large stones of the *statumen;*

upon this, the *nucleus* was formed of fragments of gravel, stone, pottery and brick mixed with lime-mortar to form a concrete, which was consolidated by ramming, and was made about six inches thick. Upon this the *summa crusta* (top crust) or *pavimentum* (hard surface) was formed of closely-jointed, irregular stones, which formed a mosaic about six inches thick, the top of which was practically on a level with the adjoining natural surface of the ground.

In and near the cities the *pavimentum* was formed of larger irregular blocks of basalt, or porphyry or lava, two to two and one-half feet in length and width and twelve inches to fifteen inches in thickness, which were dressed and fitted together with extreme accuracy and were bedded in cement.

In a general way there were thus used various materials and varied methods, none of which showed any attempt at drainage of the subgrade, and all of which were wasteful of the materials and labor, which then cost nothing but the lives of captives, who were forced to build these highways for the armies of their conquerors.

The results were roads which were remarkable for their strength and durability and for little else. If anyone were so unwise as to attempt to build similar roads now, the cost would be from four to eight times the present cost of our most expensive modern pavements which are, in every way, better for modern uses, and upon which the cities of the United States are estimated to have expended half a billion of dollars.

STONE WHEEL-TRACKS.

This peculiar form of stone pavement has long been in use in the midst of the roughly paved streets of many Italian cities and towns, and in some of the largest Scotch and English cities, which facts probably suggested its use on the Albany and Schenectady turnpike in 1833, when wheel-tracks, which are still in use, and which are here shown by a photograph taken in 1901, were built on two miles of the worst parts of this main highway to the West, and which were later made to cover the dry and sandy parts of the fourteen miles between the two cities.

There are, in 1902, no memories among the oldest residents along the road and no published accounts in local histories, of the origin and details of this interesting pavement, and those which are here given were only found by search amidst a mass of old letters and papers which were saved from an abandoned gate-house by Wheeler B. Melius Esq. of the Albany Historical Society.

The turnpike itself was opened to travel in 1805, being made twelve feet wide of gravel at a cost of $8,400 per mile. After ten years of attempts to maintain this gravel road under the traffic of many heavy narrow-tired wagons drawn by four or six horses, a "sunken pavement" of cobbles was built on the dry and sandy parts of the road, and broken quarry stone to the depth of twelve inches, was "bedded" on the wet and clayey parts, the edges being "bonded" by lines fifteen to sixteen feet apart, of small boulders twelve inches to twenty-four inches in diameter embedded in the earth along each side. Under date of January 8, 1831, the President and Directors of the Turnpike Company reported to the Legislature that they had "hitherto been unable to render said road hard and solid and to keep the hard materials (gravel, broken quarry-stone and cobbles) on the surface of the earth." In April, 1831, strenuous protests were made by the stockholders of this Turnpike Company, Chancellor Kent among others, against the effect of the charter granted in 1826 to the Mohawk and Hudson Railroad Company, on the ground that

> "Should the Rail Road Company succeed, their operations will necessarily diminish materially the tolls of the Turnpike Company, and thus sap the consideration upon the faith of which the latter have constructed their road."

Referring to the application of the Railroad Company for leave to run a side-track into the heart of Albany, Chancellor Kent wrote from New York under date of April 7, 1831:

> "If that would not be an interference with the rights of the Turnpike Company, then nothing would be an interference short of plowing up the Turnpike Road."

It was feared that the Railroad might eventually displace the stages, the tolls from which formed a large portion of the revenues of the previously-chartered Turnpike Company, then amounting to $5,137 per annum; one-third of which was paid out to gate-keepers and overseers and the balance was expended in repairs and occasional small dividends: the tolls were levied on a peculiar system by which a four-horse stage paid 43½ cents to enter upon the road at either end and the same amount to leave it, or 87 cents for each single trip.

The steam railroad was, however, built, and was opened to operation on September 12, 1831, as the first exclusively passenger railroad in the world. The handling of freight by the railroad was not begun till December 6, 1832, as detailed in a letter from the manager to the president, when three cords of wood, making two car-loads, were taken to Albany, and were the first freight carried on what is now the New York Central Railroad. In order to compete with the railroad, the Turnpike Company then made many efforts to arrange to build another railroad of their own along the side of the turnpike,* and the failure of these efforts resulted in deciding, in 1832, to lay the "stone rails," of which twenty thousand linear feet were brought from Whalen's limestone quarries at Flint Hill, eight miles up the Mohawk valley from Schenectady, and were laid in 1833 and 1834, and extended later. Sections of this stone wheel-track, in some cases half a mile or more in length, are still in good condition and in daily use, as shown in the photograph made in 1901.

The "stone rails" were made four inches thick and were roughly cut eighteen inches to twenty-four inches wide, of any length from two to eight feet, with square ends to be laid close together and with both faces flat to permit of turning over when worn. The slabs now show a concave surface worn one to two inches at the center. They were bedded in the gravel and broken stone of the roadway, by two men at the rate of 125 feet per day or one and one-half cents per running foot, the cost of the stone delivered ready to lay being thirteen cents per running foot. This made the wheel tracks cost $1,530 per mile while the cobble paving two feet to three feet wide between the tracks and five feet wide on each side of the tracks cost $1,610 per mile: Forming the roadbed cost $160 per mile, or a total of $3,300 per mile completed. A few slabs which have been

* Finally accomplished in 1901–2 by building a double track electric road.

5 ft. of large cobble pavement. < 6 ft. of trackway. > 18 in. to 24 in. wide, 4 in. to 5 in. thick,

ROAD FROM ALBANY WEST TO SCHENECTADY, N. Y., 1901.
Built by Turnpike Company in 1834.

Groove worn 5 in. wide, 3 in. deep — 2 ft. wide, 6 in. thick

ROAD WEST FROM KINGSTON, ULSTER CO., N. Y., 1902.
Built by Turnpike Company in 1862.

STONE WHEEL-TRACKS.

broken have from time to time been replaced by old blue-stone curbs from Albany.

About 1862, a system of similar wheel-track roads was begun in Ulster County, N. Y., when Davis Winne built a blue-stone track-way as a toll-road from Kingston eight miles up the Delaware and Ulster Valley to the blue-stone quarries in the Catskill mountains. This proved to be so successful that branches, and other roads of the same sort, were soon built and are still in decreasing use.

The ease of traction on these smooth slabs led to an increase of the loads drawn upon them, until eight tons has been and is an ordinary load for two horses to bring from the quarries in the hills to the wharves at Kingston and Rondout. Loads of twelve to fourteen tons drawn by three horses are now of daily occurence, and loads of seventeen tons actual weight have sometimes been drawn by four horses: all loads being weighed to determine the tolls.

These great loads were formerly carried upon narrow tires of one and one-half to two inches which speedily cut furrows in the hard stones, so that the slabs six to eight inches thick were cut through in three or four years and required renewal. Along the roadsides are now many such slabs cut nearly through and laid aside, while all the slabs which are in use show furrows ranging from one to five inches deep and three to four inches wide.

A railroad now parallels and crosses this highway reaching the quarries or passing near them. Wide tires, which are required in the river cities and towns, are used on all wagons carrying these loads, so that four-inch slabs of blue-stone are now used for renewals of the wheel-tracks and cost ten cents per running foot of slabs twenty-four inches wide. The actual cost of the original wheel-track road built in 1862 was about $3,000 per mile; the high prices induced by the War increasing the cost fifty per cent over the contract-price made in 1861.

MODERN PAVEMENTS.

Comparative loads.—In considering the desirability of the different road-surfaces and pavements, it may be noted that a team drawing one ton on a good dirt road can, with the same effort, take two tons over a good macadam surface. Passing from this to a good block-stone pavement, six tons could be drawn as easily, and this load can be increased to eight tons on good wood-block or new vitrified brick, or to ten tons on a bituminous macadam or an asphalt pavement.

COST OF PAVEMENTS.

The following table shows the conditions and costs in 1894 in the 32 cities named, 8 of which had wood-block pavements, 27 of which had sheet-asphalt pavements, and all of which had block-stone, six having sandstone, and the rest granite. The conditions and costs in 1901 are shown in detail in the several chapters.

TABLE.

CITY AND STATE.	Block-Stone.		Sheet Asphalt.		Wood.	
	Granite.	Sandstone.			Cedar-block.	
	Cost, Sq. Yard.	Cost, Sq. Yard.	Miles.	Cost, Sq. Yard.	Miles.	Least Cost.
Albany, N. Y.	$2 90			$3 12		
Allegheny, Pa.	3 37			2 75		
Atlanta, Ga.	1 49			3 00		
Boston, Mass	3 90		4	3 30		
Brooklyn, N. Y.	2 33		11	3 00		
Buffalo, N. Y.		$3 25	150	3 50		
Chicago, Ill.	3 00		24	2 90	648	$1 10
Cincinnati, Ohio	4 20			3 00		
Columbus, Ohio	3 71		11	2 54		
Denver, Col.	3 40		4	2 35		
Detroit, Mich.	4 25			3 20		
Kansas City, Kan.	2 74		2	2 55	26	1 50
Kansas City, Mo.		2 90	16	2 80	43	1 35
Milwaukee, Mis.	2 37			2 93	47	1 05
Minneapolis, Minn.	1 67		2	2 75	63	76
Nashville, Tenn.	2 40					
New Orleans, La.	4 75		8	3 65		
New York, N. Y.	3 50		52	3 00		
Omaha, Neb.	2 32		23	2 68	38	1 52
Oswego, N. Y.		2 45				
Philadelphia, Pa.	2 41			2 50		
Pittsburg, Pa.	2 38			3 35		
Portland, Me.	2 00					
Providence, R. I.	3 25			2 65		
Rochester, N. Y.		1 90 3 00	9	2 60		
San Francisco, Cal.	2 00					
St. Paul, Minn.	2 05			2 70	30	1 10
Syracuse, N. Y.	1 15	3 00	4½	2 45		
Toledo, Ohio	3 56		10	2 50		
Utica, N. Y.	3 20	2 50		1 95½		
Washington, D. C.	3 15		125	2 25		
Wilmington, Del.	2 08					
Average of prices	$2 90	$2 71		$2 81		$1 19

PAVEMENTS FOR STEEP GRADES.

In selecting a pavement for a given street of which the grade cannot be improved, the choice will often be limited by the fact that the grade is too steep to permit the use of a pavement which might otherwise be preferred.

The most useful information on the subject can be obtained from the teamsters and horsemen of cities in which different pavements on varying grades have been in use. If it is generally agreed that certain pavements are shunned by teamsters because their horses slip and fall when going down a certain street with a load, it will evidently be unwise to repeat the construction of the same kind of pavement with equal slope in a similar climate.

Under the headings of "Asphalt," "Brick," and "Broken Stone," there are given numerous instances of extremely steep grades upon which these pavements are actually built in various cities named. Examinations of these may furnish to the observer conclusive reasons for or against copying them, or may suggest changes in detail which would give better results. In examining these steep grades, it should be borne in mind that the selection of a pavement for a given street may have been made directly or indirectly by the property owners, who have not necessarily chosen the pavement best suited to attract traffic, but who, preferring a quiet street, sometimes select a pavement which traffic will shun.

Sheet Asphalt.—The practical limit of slope for business streets paved with asphalt is 4 feet per 100 feet, though any slope steeper than 3 feet per 100 feet is not advisable on a main thoroughfare.

On residence streets grades as steep as six per cent. are common, and much steeper ones often occur as shown on page 118: The residents accepting the inconvenience resulting from a few days of icy roadway because of the many and great advantages during the rest of the year.

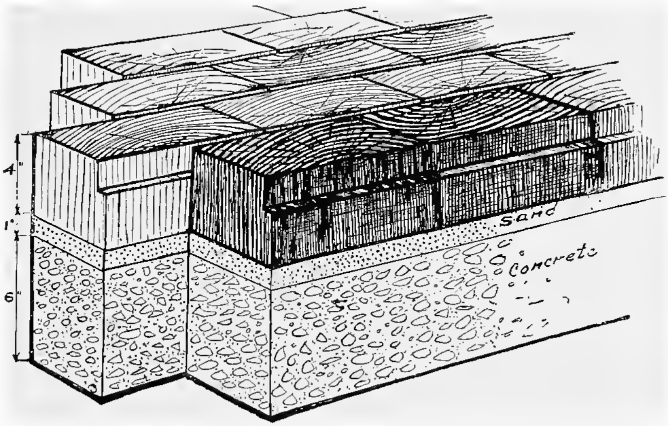
On semi-business streets having steep grades, it is a common and good arrangement to lay a sixteen feet asphalt roadway in the center, with an 8-foot strip of block-stones or chamferred bricks, or grooved-joint wood blocks, on each side. In Syracuse, N. Y., on East Genesee street, and on Bellevue avenue, this was done in 1897–8, using Medina sandstone blocks. In some cases where this has been done, the asphalt has been used almost exclusively.

Even on flat streets, however, in cold, misty weather, horses slip badly, so that in Washington it is common to remove the shoes from horses in winter because the hoofs slip less. In Brooklyn, on Christmas, 1901, many delivery-wagon horses were seen with burlaps tied over their hoofs to give foot-hold on the asphalt.

There will be parts of two or three days during most winters when this difficulty will occur with both asphalt and brick, both on steep and on level streets unless sand is strewn.

Vitrified Brick.—No complaints are made of slipping upon grades of five per cent, but these will be more or less slippery as soon as this slope is exceeded, without regard to ice. Observations show that horses begin to slip on brick as soon as the grade reaches six per cent, and that for any slope over five per cent it will be advisable to use special brick having a beveled top affording a foot-hold in the joints, which should be filled with asphaltic cement and sharp sand. With this precaution vitrified brick can be used on slopes as steep as are shown on page 98.

Creosoted Wood Block.—The same general conditions apply to these as to asphalt for the grades less than three per cent, provided sharp sand is strewn over the surface when needed, as for asphalt.



For grades steeper than three per cent, the special grooved joint here shown in detail is filled with asphaltic cement and coarse sharp sand, and this gives as good a foot-hold as grooved brick.

Block Stone.—This may be used in its ordinary form upon slopes less than ten per cent, but for this slope and greater, the blocks should have chamfered tops and special joints to give better foothold. The best manner of construction is detailed on page 61.

Broken Stone.—The maximum grade of macadam is fixed rather by the difficulties of maintenance than by conditions which govern the other pavements. Any grade steeper than five per cent offers increased difficulties from the wash of storm-water, although many instances are given on pages 164–166, where these actual steep grades were accepted by the engineers who built these roads as being unavoidable features which would have been changed if possible.

Bituminous Macadam.—Aside from the general merits of this new construction described on page 131, bituminous macadam seems specially adapted to meeting the difficulties which have heretofore attended or prevented the use of ordinary macadam on steep grades. While it presents the rough surface necessary for a secure foot-hold on steep slopes, it does not give any chance for toe-calks to loosen it or for storm-water to gully it, and these features specially commend it to experienced and critical road-builders like the one quoted on page 137.

CROWN OF PAVEMENT.

The ideal road-surface for a rainless climate would be flat, but the practical road-surface for all weathers must be curved or "crowned," in order to quickly shed water to the gutters. This is the sole reason for giving a "crown," and it is therefore logical to reduce the amount of curvature when the slope of the street gives the needed drainage.

To suit the crown to the slope, engineers have made frequent use of the formulæ devised in 1898 by Andrew Rosewater, M. Am. Soc. C. E., city engineer of Omaha, Neb., by which the crown is computed for any width and any grade: the amount of crown decreasing as the slope increases.

The 1898 formulæ are as follows:

For Brick, Stone and Wood block $= C = \frac{W}{1600}(20-f)$

For Sheet-asphalt, $C = \frac{W}{600}(9-f)$

C = crown of pavement in feet,

W = distance between curbs in feet,

f = grade of street in feet per 100.

STANDARD CROWNS BY FORMULÆ OF 1898.

DISTANCE BETWEEN CURBS in feet.	FOR BLOCK-STONE, BRICK AND WOOD-BLOCK Crown given in hundredths of feet. Grade of street in feet per hundred.								
	LEVEL.	1	2	3	4	5	6	7	8
20	25	24	23	21	20	19	18	16	15
25	32	31	29	27	25	24	22	21	19
30	38	36	34	32	30	29	27	25	23
35	44	42	40	38	35	33	31	29	27
40	50	48	45	43	40	38	35	33	30
45	57	54	51	48	45	43	42	37	34
50	63	60	57	54	50	47	44	41	38
55	69	66	62	59	55	52	48	45	42
60	75	72	68	64	60	57	53	49	45
65	87	78	74	70	65	61	57	53	49
70	88	84	79	75	70	66	62	57	53
75	94	90	85	80	85	71	66	61	57
80	100	95	90	85	80	75	70	65	60

Steeper than 8 per cent, the same Crown as for 8 per cent.

DISTANCE BETWEEN CURBS in feet.	FOR SHEET-ASPHALT Crown given in hundredths of feet. Grade of street in feet per hundred.					
	LEVEL.	1	2	3	4	5
20	30	27	23	20	17	13
25	38	33	29	25	21	17
30	45	40	35	30	25	20
35	53	47	41	35	29	23
40	60	54	47	40	34	27
45	68	60	53	45	38	30
50	75	67	59	50	42	33
55	83	73	64	55	46	37
60	90	80	70	60	50	40
65	98	87	76	65	54	43
70	105	94	82	70	59	47
75	113	100	88	75	63	50
80	120	107	93	80	67	53

Steeper than 5 per cent, the same Crown as for 5 per cent.

1902 *Formulæ.*—Observations since 1898 have convinced Mr. Rosewater that American sheet-asphalt pavements should have the maximum crown practicable for traffic, as a means of protection against the standing of water in the small surface depressions.

Observation also suggested to him an increase of crown of all pavements on various gradients because, under the 1898 formulæ, the pavements on grades varying from three to eight per cent failed to shed water to the gutters quickly enough to prevent freezing in sleety weather, or to avoid its spreading in warm weather.

To meet these objectionable conditions, radically different formulæ have been devised in 1902 by Mr. Rosewater as substitutes for those of 1898.

The 1902 formulæ are as follows:

For brick, stone-block, wood-block and compressed European rock-asphalt, $C = \frac{W(100 - 4f)}{6000}$

For American sheet-asphalt (composed of sand and asphalt or of compressed natural sand-rock), - - - $C = \frac{W(100 - 4f)}{5000}$

C = crown of pavement in feet,

W = distance between curbs in feet,

f = grade of street in feet per 100.

Standard Crowns by Formulæ of 1902.

Distance between Curbs in feet.	For Block-stone, Brick and Wood-block. Crown given in hundredths of feet. Grade of street in feet per hundred.														
	Level.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
20	33	32	31	29	28	27	25	24	23	21	20	19	17	16	15
25	42	40	38	37	35	33	32	30	28	27	25	23	22	20	18
30	50	48	46	44	42	40	38	36	34	32	30	28	26	24	22
35	58	56	54	51	49	47	44	42	40	37	35	33	30	28	26
40	67	64	61	59	56	53	51	48	45	43	40	37	35	32	29
45	75	72	69	66	63	60	57	54	51	48	45	42	39	36	33
50	83	80	77	73	70	67	63	60	57	53	50	47	43	40	37
55	92	88	84	81	77	73	70	66	62	59	55	51	48	44	40
60	100	96	92	88	84	80	76	72	68	64	60	56	52	48	44
65	108	104	100	95	91	87	82	78	74	69	65	61	56	52	48
70	117	112	107	103	98	93	89	84	79	75	70	65	61	56	51
75	125	120	115	110	105	100	95	90	85	80	75	70	65	60	55
80	133	128	123	117	112	106	101	96	91	85	80	75	69	64	59

Distance between Curbs in feet.	For Sheet-Asphalt. Crown given in hundredths of feet. Grade of street in feet per hundred.												
	Level.	1	2	3	4	5	6	7	8	9	10	11	12
20	40	38	37	35	34	32	30	29	27	26	24	22	21
25	50	48	46	44	42	40	38	36	34	32	30	28	26
30	60	58	55	53	50	48	46	43	41	38	36	34	31
35	70	67	64	62	59	56	53	50	48	45	42	39	36
40	80	77	74	70	67	64	61	58	54	51	48	45	42
45	90	86	83	79	76	72	68	65	61	58	54	50	47
50	100	96	92	88	84	80	76	72	68	64	60	56	52
55	110	106	101	97	92	88	84	79	75	70	66	62	57
60	120	115	110	106	101	96	91	86	82	77	72	67	62
65	130	125	120	114	109	104	99	94	88	83	78	73	68
70	140	134	129	123	118	112	106	101	95	90	84	78	73
75	150	144	138	132	126	120	114	108	102	96	90	84	78
80	160	154	147	141	134	128	122	115	109	102	96	90	83

Under the heading of "Asphalt," page 118, and "Brick," page 95, will be found the record of the actual present practice for crown on level grades and 30 feet width in the cities named.

Form of Crown.—The form of crown should be a parabolic curve nearly flat at the center, for traffic, and sloping more quickly toward the sides, for drainage.

When the amount of crown has been computed from a formula or a table, or when an experienced engineer has preferred to determine it arbitrarily, as is very often well done, the form of the curve can be determined thus for any width or crown: divide the space from center to curb into twelve equal parts. Take the center ordinate, or total "crown," as unity; then the successive ordinates, measured up from the base-line, will be: At center, 1.00, .99, .97, .94, .89, .83, .75, .66, .55, .44, .30, 16, .0 at curb. Or stretch a line from curb to curb on level with the center, and measure down the corresponding amount. Thus if the width is 30 feet from curb to curb, and the crown has been determined to be half a foot, the ordinates measured down at intervals of 1¼ feet will be in inches and decimals. At the center 0 inches—0.06, 0.18, 0.36, 0.66, 1.02, 1.50, 2.04, 2.70, 3.36, 4.20, 5.04, 6.00 inches at curb. This shows a side-slope of about five per cent on the third next the curb. These figures may be useful in making a template for fixing the curve of a pavement-surface, or for forming the sand-cushion of a brick pavement as described on page 95.

For Macadam, it is usual to consider that the conditions to be met are reversed, and it being necessary to prevent storm-water from following the road-surface,

VANDENBURGH AVENUE, TROY, N. Y., 1901.
Surface of two inches of trap on base of four inches of limestone.

the "crown" for macadam is increased as the slope increases; one-half inch per foot being usual on level grade, and a maximum of three-quarters inch per foot on steep slopes, increasing to one inch on excessive slopes. This produces in theory a ridge in the center, with a straight slope of 5½ inches on each side for a level 22 foot roadway. But in practice, the roller flats the central "ridge" down, and produces a curve which is flat in the center and slopes most at the sides, which is the form desired.

FALLS ON DIFFERENT PAVEMENTS.

As to the relative liability to accidents from slipping of horses' feet upon different pavements, observations were made for Captain (now General) Francis V. Greene, M. Am. Soc. C. E., during a period of six months on thirty-six various streets in ten different cities, viz.: New York, Philadelphia, Chicago, Boston, St. Louis, New Orleans, Washington, Buffalo, Louisville and Omaha. The result of these observations, and of similar ones made by Col. William Haywood, M. Inst. C. E. in London, by George F. Deacon, M. Inst. C. E. in Liverpool and by French engineers in Paris, were read before the Am. Soc. C. E. on December 16, 1885.

Over 800,000 horses and 81,000 miles of travel were observed in the ten cities of the United States, with the result of showing that a horse may travel, for each fall that occurs —

272 miles on wood-block pavement.

413 miles on granite-block pavement.

583 miles on sheet-asphalt pavement.

These results in the cities of the United States differ radically from those obtained for Colonel Haywood, in London, where it was required that horses should be smooth-shod, instead of having the sharp toe-calks which are generally used in the United States, and where European rock-asphalt is used instead of Trinidad asphalt and sand. The results observed in London were —

446 miles on wood-block pavement.
132 miles on granite-block pavement.
191 miles on sheet-asphalt pavement.

CULVERTS.

To carry water beneath a roadway, culverts are variously built of cast-iron pipes, of masonry, of concrete and of double-strength vitrified pipe.

The bottom-line of culverts is usually fixed at the bottom-grade of the side-ditches so that the available height is limited, and large waterway is often obtained by using two, and sometimes three, parallel lines of 18, 24 or 30-inch pipes.

If the ditch drains a hillside having a southern exposure, the midday sun of winter will supply a trickle of water which will freeze at night, and under this condition such pipe culverts will soon freeze solid and sometimes burst.

For most conditions, box-culverts of rubble masonry or of monolithic concrete with embedded expanded metal in the covers, are much preferable to pipes, being less ready to freeze and less liable to be damaged if frozen.

For equal areas of waterway and depending upon the local conditions of stone-supply and freight rates, the relative costs will usually be in the order first named above.

When the span of a masonry culvert is two feet or more and 6-inch to 8-inch cover-stones are used, they should be carried on suitable I-beams placed two feet centers, in order to carry ordinary traffic safely. If there is height enough a rough stone arch may be best and cheapest.

CURBS.

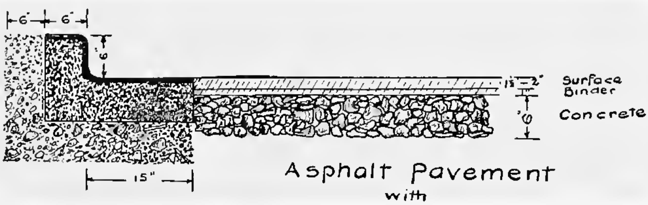
Curbs should be set or re-set before beginning the pavement of which they are a necessary adjunct. The trench for the curb should first be cut and graded, and sub-drained if needed, and if concrete foundation for the curb is proposed, the curb-stones should be accurately aligned and graded upon fragments of stone, around and over which the concrete is to be formed and tamped: the pavement-base, if any, and the pavement itself being afterward formed against the face of the curbs.

Curbs are used of various materials which are somewhat as follows for the different sections of the United States; there being noticed a general tendency toward the use of concrete.

Kinds.—For the New England States, granite and also concrete. For New York and the cities along the Hudson and the coast, and for Washington in part, "bluestone" (a tough sandstone) from Ulster county, N. Y., and limestone and also concrete, of which there was built 202 miles in the Borough of Brooklyn during 1900. For central, southern and western New York, and for adjacent Ohio and Pennsylvania, Oxford "bluestone," from Chenango county, N. Y., and Medina sandstone, from Orleans county, N. Y., and limestone, and also concrete.

For the western and southern cities, granite, and sandstone from Kettle River, Minn., and from Berea, Ohio, and from Colorado, and also concrete, the latter being much used in Chicago, St. Paul, and Cleveland. Brick curbs are used with brick pavements in Louisiana and Texas, and have been observed in two northern towns in connection with brick gutters for macadamized streets. These were special brick, 2¼-inch by 4½-inch by 8½-inch, with one corner rounded, set on end upon concrete with the edge toward the roadway and showing 4½ inches above the paved gutter: they seemed to be poor substitutes for stone or concrete, as the material is unsuited for the purpose: this opinion is confirmed by Willis Fletcher Brown, consulting engineer of Toledo, Ohio, whose extended experience with brick pavements is well known.

Sizes.—The dimensions of stone curbs vary in the cities from sixteen to twenty-four inches for depth, five to six inches for thickness, and three to five feet for length. The top is always beveled to take the slope of the sidewalk to the gutter.



Asphalt Pavement
with
Combined curb and gutter

Concrete curb is usually moulded in place in uniform lengths, varying from four to ten feet, preferably five feet, with ⅛ inch joints formed by the removal of temporary steel templates. It is often made in combination with a 12-inch to 15-inch gutter, and it is recent and good practice to add a cast iron or a steel guard-strip, or "rub-strip," anchored two inches into the concrete by a 2-inch by ¼-inch perforated web, and showing a rounded flat surface of 1 ½ to 2 inches on the outer top edge, to protect against the impact of wheels.

Corners are usually curved on radii varying from four feet to nine feet; the former preferred for streets of moderate traffic.

COST.

Straight curbs set cost about as follows, with thirty per cent to fifty per cent added for curves:—

Granite, 50 cents to 90 cents and in some cases $1.25 per linear foot. Ulster or Oxford bluestone, 40 cents to 80 cents and in some cases $1.00 per foot. Medina or Berea sandstone 35 cents to 70 cents. Concrete usually costs from 40 cents to 50 cents, with 35 cents added for a combined gutter, though combined curb and gutter have been built for 50 cents.

The prices vary widely with the freight-rates and the local conditions.

CAR TRACK CONSTRUCTION.

When any of these pavements are to be built on a street containing car-tracks, special attention must be given to the reconstruction of the track and to the details of the pavement next to the rails. The pavement between the rails, and for two feet on each side of them, should be built by the railroad company under the plan and direction of the city engineer, or this should be done by the city at the expense of the railroad, as in Rochester, N. Y. The methods there used in 1900 are shown in the picture here given.

This construction with heavy rails is necessary to make the track-structure as rigid as possible, and this is so well accomplished in 1901 that sheet-asphalt is laid in actual contact with both sides of the rails, upon which exceptionally heavy cars pass without cracking the asphalt. This is seen at the best in Buffalo, N. Y., where the rails are electrically spliced in place, by welding three-inch by one-inch by fifteen-inch steel plates on both sides of each joint, forming continuous ninety-pound rails for great lengths. Joints are cast with molten iron with similar effect at Chicago, Brooklyn and Minneapolis, and many other cities where the authorities and the railroads work together to get the best results in their pavements.

TRACK AND PAVEMENT CONSTRUCTION, ROCHESTER, N. Y., 1900.

Medina sandstone block pavement on six-inch natural cement concrete base, and trolley-railway track-construction on concrete foundations. Three-inch porous tile beneath concrete and leading to sewers; Ties two-feet centers, on concrete five inches thick, with twelve inches of concrete between the ties; Nine-inch full-grooved steel girder-rails, bonded, resting upon the ties and upon twelve inches of concrete between the ties.

CONCRETE BASE FOR PAVEMENT.

A concrete base, four to six inches thick, is desirable, whether the wearing-surface is to be of asphalt, or of creosoted wooden blocks, or of vitrified brick, or of stone blocks. The wearing-surface will need repairs and renewals, but a properly-made concrete base will be permanent, and will always increase in strength and solidity. It is specially needed wherever the street is of recently made ground, or where it was formerly swampy or unstable, or where traffic is expected to be heavy, unless an old stone pavement is in place to serve as a substitute.

SUBGRADE.

Before forming the subgrade to receive the concrete base, all present and prospective sewer, water and gas and subway connections should be made and extended under the curbs, and all old and new trenches should be tested with a ten-ton roller, and depressions should be filled and wetted and tamped until solid.

HYDRAULIC CEMENT.

The manufacture of American Portland cements has increased from one-third of a million barrels in 1890 to ten million barrels in 1900, and the manufacturers have meantime raised their standards, improved their products and reduced their prices to keep pace with the growing demand for the highest grades which were formerly only made abroad.

The differences in price between the high-grade reliable cements and the low-grade uncertain ones are comparatively small, and the poor cements will disappear from the market when all engineers make tests and are guided by the results.

Good natural cements are still much used, as appears from the table at page 56, and they are better than low-grade Portland cements, as well as being cheaper.

CEMENT TESTS.

The engineer of a small city will seldom have time or outfit for the complete tests now usual on large works, for which there are needed a special man with an expensive equipment installed in a separate room.

The following described simple tests can be made by the engineer himself, with an outfit costing not over four dollars and which can be stored in a desk pigeonhole. The tests thus made will be interesting in themselves, and will be effective and convincing aids in rejecting most bad cements which may be offered, and will also have the preventive effect of causing manufacturers to send their lower grades of cement elsewhere and to send only their best products to the places where such tests are probable:—

First.—*For fineness.*—Sift three to four ounces of cement through a standard test seive of 100 meshes per linear inch. Reject cement of which ten per cent by weight is retained on the seive. This is conservative and the limit may be made smaller, for many Portland cements are now in the market which will leave less than four per cent. A test by 200-mesh seive with a thirty per cent limit is desirable but takes time.

Second.—*For quickness of setting.*—Make a pat of four ounces of neat cement adding one-quarter to one-fifth its weight of water and making a putty-like ball which can be dropped on the table and retain its form without falling to pieces. Press this upon a three by four inch glass plate leaving it half an inch thick in the center and sloping to thin edges all around. Note time required to take initial set. Reject cement which sets in less than twenty-five minutes. It may take three hours or more, but it will be better for paving if it sets in one hour. The instant of "initial set" is determined by noting when the surface will support a four-ounce weight resting upon the smooth flat end of a one-twelfth inch diameter wire.

Third.—*For soundness.*—Use the pat on glass above described and note when it sets enough more to make it difficult to indent it with the thumb nail, or when it will support one pound on the smooth flat end of a one-twenty-fourth inch wire, which may be considered as indicating "a hard set." Then put the pat with its glass plate over boiling water until the steam has heated them, and then immerse and keep them in the boiling water for three hours. Reject Portland cement if the pat shows radiating cracks in the center, or shows blow-holes on the surface, or curls up from the glass or cracks at the thin edges. Good natural cements may fail to endure this test (which is a severe one), and it may properly cause the rejection of some Portland cements which would endure it after being "air-slacked" or "seasoned."

Fourth.—*For purity.*—Provide a glass-stoppered bottle of muriatic acid; two shallow white bowls or two half-inch by six-inch test-tubes, a glass rod and a pair of rubber gloves. Put in a bowl or a tube as much cement as can be taken on a nickel five-cent piece; moisten it with half a teaspoonful of water; cover with clear muriatic acid poured slowly upon the cement while stirring it with the glass rod.

Pure Portland cement will effervesce slightly and will give off some pungent gas and will gradually form a bright yellow jelly without any sediment.

Powdered limestone or powdered cement-rock mixed with the pure cement will cause a violent effervescence, the acid boiling and giving off strong fumes until all the carbonate of lime has been consumed when the bright yellow jelly will form.

Powdered sand or quartz or silica mixed with cement will produce no other effect than to remain undissolved as a sediment at the bottom of the yellow jelly.

Reject cement which has either of these adulterants.

Powdered slag mixed with cement unfits it for pavement-work. The adulteration is indicated in the dry cement (when coloring matter does not conceal it), by a lilac tint, and it is also indicated on the surface of a test-pat after drying, by brown and green and yellow discolorations.

A chemical test will show the presence of slag if made as follows:

Provide an ounce of mixture of methylene iodide ($C H_2 I_2$) and benzine, in which the methylene (the specific gravity of which is $3.^{292}$ being the heaviest organic liquid) is reduced to the specific gravity of $2.^{95}$ by addition of benzine. The methylene is uncommon and costs a dollar an ounce.

In a half-inch test-tube put half an inch of the dry suspected cement and pour in a little of the mixture, stirring to a thin grout. Then cork the tube and let it stand. If slag is present, it will remain at top while the cement will settle to the bottom. The separation cannot be seen if coloring matter is present.

Coloring matter in any cement will show itself in the acid test by giving a black or gray color to the resultant jelly which would otherwise be yellow. The coloring matter may, or may not, be injurious in itself, but its presence shows that the manufacturer wished to disguise the cement, which should be rejected, because there are a plenty of good cements which need no disguise.

Weight.—The several kinds of cement differ materially in weight and any cement that varies much from these average weights should be examined specially.

The standard barrel contains 3.65 cubic feet and the standard bag is one-fourth of a barrel. The average weight of a cubic foot of packed cement is: Portland, 104 to 114 lbs.; puzzolan, 90 lbs.; natural, 75 to 82 lbs. for Eastern and 70 to 72 for Western: The average net weight of each per barrel being 375 lbs., 330 lbs., 300 lbs. and 265 lbs.

RESULTS.

These tests will be conclusive as far as they go, and will cause the rejection of no good cements. The makers of high-grade cements would not object to these requirements and would not increase the price because of them.

USE OF CEMENT.

The cement in bags or barrels should be delivered and stored in a tight shed two feet off the dry ground.

Blending.—The cement should never be used directly from any original barrel or bag, because there may be more or less damaged or defective packages, each of which would thus form a bad spot in the work. This chance is wholly avoided by requiring that the contents of five packages shall always be blended dry in the cement-shed before any is sent out for use, and that only this blended product shall be sent out of the shed into the work.

This will not add to the cost, but will merely keep the cement-man busier.

AGGREGATES.

The aggregates may be crushed from the cheapest stone available, though the hardest and toughest is preferable. Special care is necessary to see that the stone, before crushing, is clean and free from mud and clay. Stone unfit for masonry, or for macadam, may serve the purpose when it shall be embedded in the matrix of mortar in the concrete.

Crusher-dust as "sand."—The total product of a crusher passing through a 2½-inch screen will give the best results, provided that the crusher-dust is considered as sand, and that proper allowance is made for its presence after determining its quantity. If the stone before crushing is not entirely clean, the crusher-dust should be excluded by screening.

Clean gravel and sand may be used in lieu of stone with the same provision as to the included sand.

Where neither stone or gravel is available, as in the middle West, fragments of brick or of furnace-slag are often used as aggregates.

In any case, the number of cubic yards of loose material for the aggregate will be twelve to twenty per cent more than the total cubic yards of concrete rammed in place.

SAND.

The sand should be the sharpest and cleanest available, preference being given to pit-sand, of which the grains vary from fine to course. It will be well worth while for the engineer to examine the various sources of supply, and to be as careful in its selection as in the selection of the cement which is to be mixed with it. In a recent case, sand, which seemed fairly good, was washed and was then found to make concrete which was one-third stronger than when the sand was used in its natural state. Sand containing five per cent of loam or of clay is common and should not be used until washed. Two per cent will retard the set and perceptably weaken the mortar.

PROPORTIONS AND MIXING.

The proportions measured in loose bulk should be one part Portland cement to three parts sand to six parts of the aggregate, or one part natural cement to two parts sand to four parts of the aggregate. (See table at page 56.)

When the concrete is made by hand, the blended dry cement, described on page 47, should be mixed on a mortar-bed while dry with the due proportion of dry sand, until the color is uniform and no streaks of cement can be noticed when the dry mixture is smoothed with the back of a shovel. Water (equal in weight to eleven to twelve and a half per cent of the weight of the sand and cement for Portland cement and fifteen to seventeen per cent for natural cement) is then added gradually while mixing until plastic mortar is formed.

Meantime the rest of the men are measuring, sprinkling and spreading the aggregate in a four-inch layer upon the platform (for which a sheet of iron ten feet square is the best), and on top of the layer is spread the mortar, when the whole is turned with shovels by four men while two men work between them with specially large hoes. This mixing is continued until every face of every particle and fragment is perfectly coated with the mortar, requiring hard work which must be done rapidly.

WATER.

It is not important whether the mixing-water is pure, but it should not be muddy.

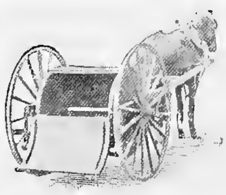
The required amount of water should vary, as the aggregates are more or less moist, so as to give a uniform result, for to be either too wet or too dry is a grave defect in concrete.

There is the widest difference of opinion among engineers of large experience as to the degree of wetness which gives the best results. All are agreed that the surplus mortar must be brought to the surface by ramming, after filling all voids. The effectiveness of ramming will vary on different works; the ease with which the mortar is brought to the surface increases with the amount of water, up to the condition where the concrete is so wet that no ramming is needed; which is bad practice, but not uncommon.

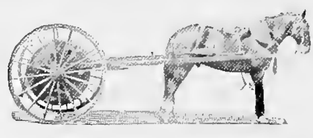
The best practice is to use the least water with which the available rammers can be made to bring the mortar to the surface. It is futile to try to secure this necessary result by the persistent ramming of concrete which has been mixed too dry, and which it were better to remix with more and wetter mortar. There should never be enough water to produce free grout, which can drain away into the subgrade and be lost.

MACHINE MIXING.

Concrete is made better and more cheaply by any of the various rotary mixers than it can ever be made by hand. It is poor practice to depend upon shovellers to proportion the materials, as is often done with continuous and with gravity mixers. The proportions should always be accurately measured. Mechanical mixers, operated by steam power, are best adapted to large concentrated masses like dams, foundations and bridge-



READY TO LOAD.

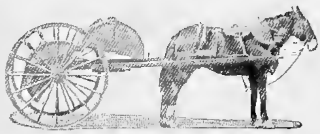


LOADED

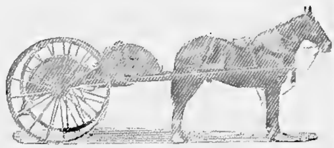
abutments, but are not well adapted to forming a thin layer spread over a large area, like a pavement-base.

This condition is particularly well met by a new device known as a "dromedary mixer," which consists of a two-wheeled cart of which the body is a cylinder, which turns with the wheels as the cart is hauled along.

The proper amounts of cement, sand, stone and water, are put into the cylinder which is closed tightly, and then the cart is hauled to the work where the perfectly mixed concrete is dumped in place and spread.

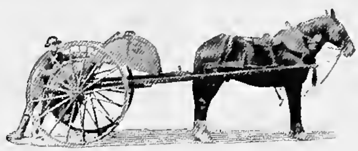


DUMPING



DUMPED

The machine is described and highly commended by the city engineer of Baltimore, Charles E. Phelps, in the Municipal Journal and Engineer, of December, 1901.



CLOSING

SPREADING AND RAMMING.

Set eight-inch boards from curb to curb, supported on edge by stakes, and enclosing a space five feet wide, within which spread the concrete in a loose layer about 7¼ to 7½ inches deep, for a six-inch base, so that a one-yard batch will fill about one-third the width of a thirty-foot pavement. Ram it at once vigorously until all voids are closed, when the surplus mortar will come to the surface and the mass will quake slightly under the rammers.

Effective ramming is hard work at which a workman should not be kept for more than an hour, when he should be changed to wheeling or turning.

Monolith.—Each day's work must be a monolith. The spreading and the ramming must be so done that each successive batch shall be rammed before the preceding and the adjoining batches have begun their first set. The stiffness of the concrete after ramming in place must be such that the fresh mass will retain its form and will not crumble when the boards are removed preparatory to filling the adjoining space. Properly managed there will be no lines between the batches, which will all be merged into one mass.

Bond.—Each day's work can also readily be bonded with the base previously formed, so that the whole will be a monolith. Form the end of each day's work on a steep two-on-one slope, or with a three-inch step and vertical rises, and have the surfaces of the end show voids between the fragments of embedded stone to afford a good bond. When work begins the next day, prepare a pail of thick grout of clear Portland cement, and brush it freely over and into the voids of the exposed end, just before dumping the fresh concrete against it.

The result of omitting these small precautions, and of making a flat slope at the end of each day's concrete-work has been known to show, a year afterwards, in well-defined waves of an inch or more in height, extending from curb to curb of an otherwise perfect asphalt pavement. These waves being resultants of a slight expansion, or "growth," of the concrete which slide upward at all the places, two hundred to three hundred feet apart, where the concrete-work for each day had ended.

SURFACE.

If it is desired to "float" the surface smooth, as is required for pavement-base in Paris, and in Sidney, N. S. W., and for curbs and gutters and for accurately-cut wood-block pavements in the United States, the surface may be formed of the matrix-mortar without the embedded stone-fragments. It is of the first importance that this surface shall be of the same mortar as the matrix of the mass, and be placed at the same time and thoroughly blended with it, and that it shall not be made of a different or better kind or proportion of cement, nor be spread afterwards as a plaster to cover a porous or rough surface. Concrete which is considered to need plastering should rather be taken out and replaced by good work.

SETTING.

When concrete has been rammed in place, it must be kept entirely undisturbed until it sets firmly, which should take from four to seven days ordinarily and longer in cold weather.

Wet.—It is of vital importance that the concrete should be kept wet during all this time, and that it be sprinkled freely at night and morning, and be covered from the sun by sand or canvass which will retain the water.

It is a common thing to find experienced foremen who fully believe that concrete should "dry out," and many pieces of otherwise good concrete have been rendered worthless by acting upon this idea which ignores the plain fact that "hydraulic" cement requires water.

Traffic of all kinds, both by foot or by vehicles, should be kept from the concrete-base for at least a week if possible, using planks to cover street-crossings where passage-ways must be permitted.

FREEZING.

Portland.—For any concrete likely to be soon exposed to frost, use Portland rather than natural cement, and if possible avoid making concrete at all during cold weather. Avoid very slow-setting cement for such work, and especially avoid using sand or gravel containing loam or clay, of which even two per cent will greatly retard the setting of any cement with which it may be mixed. Use a little more cement and a little less water than in warm weather. Make special effort to prevent the concrete from freezing, at least until it takes its first set, and, if possible, for several hours afterwards, and also prevent it from thawing after it has frozen. While mixing, keep a fire burning in the sand pile and another in the stone pile, and heat the mixing-water.

Brine.—Use brine by making a barrel of saturated solution of salt, in which keep a layer of free salt showing in the bottom; put one-tenth of the contents of this barrel, dipped from the bottom, into each barrel of fresh water heated for mixing. It is useless to provide easily broken salometers which the foremen will not use, as this simple plan more readily provides a ten-per-cent solution, which will retard freezing and which will not injure Portland cement concrete, and which, in some cases, will even increase its strength.

Limit.—Stop work when the cold reaches twelve degrees of frost or 20° Fh. If each and all of these precautions be observed, good results will be obtained, but at greater cost than for work under the normal conditions which are the basis of the following table.

COST.

The present cost of concrete in cities was compiled in 1901 in an unusually effective way by F. V. E. Bardol, M. Am. Soc. C. E. and chief engineer of department of public works of Buffalo, in the following table which is republished from "Municipal Engineering."

These figures and this table do not include the four-inch base for five miles of sheet asphalt pavement built during 1895 to 1899, in the city of Niagara Falls, N. Y., by Walter Jones, city engineer, in proportions of one Portland cement, five sand and ten stone, at a total cost per cubic yard, in 1897, of $4.00. The items were:

1-10 cubic yard (or 68% of a 4-foot barrel) of high grade Portland cement, at $1.75 per barrel	$1 20
5-10 cubic yard of graded pit-sand, fine to coarse, at $1.10 per cubic yard	55
1 cubic yard of crushed and dust-screened limestone at $1.25 per cubic yard	1 25
Mixing and placing and ramming "dry"-mixed concrete, one cubic yard	1 00
Total per cubic yard	$4 00

The results were good.

Portland Cement.—Of forty-two cities, one-third use Portland cements in the proportions of one cement, three sand and six to seven stone or gravel, at an average cost, for twelve cities, of $5.30 per cubic yard.

Natural Cement.—Two-thirds of these forty-two cities use natural cements in the proportion of one cement, two sand and four to five stone or gravel, at an average cost, for sixteen cities, of $3.85 per cubic yard.

Cost of Extra Work.—The cost of materials makes up seven-eighths of the expense of concrete, so that the extra precautions which have here been indicated and which may increase the labor ten per cent, will add little to the cost per cubic yard of the result.

COST OF ASPHALT PAVEMENTS INCLUDING BASE, BINDER, WEARING SURFACE.

COMPILED BY F. V. E. BARDOL, BUFFALO, N. Y., JANUARY, 1901.

CITY.	Average price for 1900, including concrete, binder and wearing surface.	Thickness of concrete.	Proportions of concrete.	Cost of concrete per cubic yard.	Correction for concrete, Buffalo specifications.	Kind of cement.	Cost of cement per bbl.	Cost of sand per cu. yd.	Cost of broken stone per cubic yard.	Depth of binder.	Correction for binder, Buffalo specifications.	Thickness of wearing surface.	Correction for wearing surface, Buffalo specifications.	Period of guarantee.	Correction for guarantee, Buffalo specifications.	Hours of labor.	Prevailing rate of wages, common labor.	Correction for labor, Buffalo rates.	Price per sq. yd. reduced to Buffalo specifications. (See foot-note.)	City Engineer.
Altoona	$2 47	6"	1-2-5	$4 20	— 14	Natural	$0 80	$1 55	$1 68	1"	+ .10	1½"	— .19	5 yrs.	+ .15	10	$1 60	+ .04	$2 81	Harvey Lioton.
Atlanta	2 83	6"	1-2-4	4 50	—.10	"	1 00	75	1 25	1½"	0 00	1½"	+ .19	10 "	0.00	10	1 00	+ .10	3 02	R. M. Clayton.
Baltimore	2 18	6"	1-3-5	3 30	0.00	"	1 00	75	1 50	1½"	0 00	2"	0.00	5 "	+ 15	8	1 66	0.00	2 33	B. T. Fendall.
Boston	3 25	6"	1-3-7	4 50	— 24	Portland	2 50	1 30	1 70	1½"	0.00	1¼"	+ .19	10 "	0.00	9	1 75	0.00	3 20	B. T. Wheeler.
Brooklyn	3 15	5"	1-3-6	5 63	—.17	Portland	2 20	$.75 to $.80	1 60	1"	+ .10	2"	0.00	10 "	0.00	8	1 50	0.00	3 08	Geo. W. Tilson.
BUFFALO, N. Y.	2 20	6"	1-2-5	3 30	.....	Natural	70	$1 25	1 10	1½"	.....	2"	.....	10 "	...	8	1 50	.....	2 20	F. V. E. Bardol.
Chattanooga	2 68	6"	1-2-5	....	0 00	"	....	....	....	.....	.....	2½"	— .19	5 "	+ .15	...	...	...	2 64	Robt. Hooke.
Cincinnati	2 05	6"	1-2-6	2 80	—.03	"	60	75	1 35	†½"	+ .10	2"	0.00	5 "	+ .15	10	1 50	+ .05	2 32	H. J. Stanley.
Cleveland	2 17	6"	1-2-4	....	.00	"	....	....	....	1"	+ .10	2"	0.00	10 "	0.00		....	...	2 27	James Ritchie.
Columbus	2 20	6"	1-2-4	3 00	— .11	"	80	1 00	1 10	1"	+ .10	2"	0.00	10 "	0.00	10	1 50	+ .05	2 24	J. Griggs.
Denver	2 13	6"	1-2-4	4 50	— .20	"	1 25	50	2 00	1"	+ .09	2"	0.00	5 "	+ .15	8	1 60	0.00	2 17	W. P. Jones.
Des Moines	1 96	4½"	1-2-4	....	+ .10	"	....	40	1 25	1"	+ .10	1½"	+ .19	7 "	+ .09	10	1 75	+ .02	2 46	G. E. Eberhart.
Fort Wayne	2 40	6"	1-2-5	....	0.00	"	....	65	1 15	1½"	0.00	2"	0.00	10 "	0.00	10	1 50	+ .05	2 45	F. M. Randall.
Kansas City	2 12	5"	1-2-5	....	+ .03	"	....	80	1 00	1¼"	0.00	1½"	+ .19	10 "	0.00	8	1 40	+ .03	2 37	R. M. Waddell.
Lafayette, Ind	2 00	6"	1-2-6	4 00	— .11	Portland	....	....	....	1"	+ .10	1½"	+ .19	10 "	0.00	10	1 50	+ .05	2 23	W. K. Eldridge.
Los Angeles	1 80	6"	1-3-6	6 00	— .21	"	2 50	40	1 00	No	+ .28	2"	0.00	No	+ .18	10	2 00	— .01	2 04	F. M. Olmstead.
Milwaukee	1 85	6"	1-2-5	....	+ .04	Natural	55	65	1 10	1"	+ .10	2"	0.00	5 "	+ .15	10	1 50	+ .05	2 19	C. J. Poetsch.
Montreal	3 25	6"	1-3-4	6 00	— .45	Portland	2 84	75	1 25	½"	+ .19	2½"	— .19	10 "	0.00	10	1 25	+ .07	2 87	John R. Barlow.
New Orleans	2 50	6"	1-3-7	8 00	— .40	"	....	2 02	2 02	1½"	0.00	2"	0.00	5 "	+ .15	10¼	1 50	+ .05	2 30	W. J. Hardee.
Newport News	2 63	6"	1-2-5	4 80	— .25	Natural	95	50	2 20	1½"	0.00	1½"	+ .19	10 "	0.00	10	1 25	+ .08	2 65	T. C. Hatton.
New York	2 55	6"	1-3-6	5 837	— .15	Portland	2 50	45	....	1"	+ .10	2"	0.00	10 "	0.00	8	2 00	— .07	2 44	Jacob Wund.
Omaha	2 11	6"	1-2-5	5 00	— .03	Natural	$.85 to $.75	$.65 to $.75	$1.35–$1.45	1½"	+ .00	1¼-2"	+ .10	5 "	+ .15	10	1 65-1 85	+ .02	2 35	A. Rosewater.
Peoria, Ill	1 96	6"	1-1¼-4	4 50	0.00	"	55	1 00	1 50	1"	+ .10	1½"	+ .19	5 "	+ .15	10	1 50-1 75	+ .02	2 42	H. E. Beasley.
Pittsburg	2 44	6"	1-2-4	......	— .15	"	70	65	1 70	1"	+ .10	2"	0.00	5 "	+ .15	9-10	1 50-1 60	+ .04	2 58	G. W. Wilson.
Providence, R. I.	2 65	6"	1-2-6	5 10	— .29	Portland	2 20	.50 to .75	2 00	1½"	0.00	1½"	+ .19	5 "	+ .15	10	1 50-1 75	+ .05	2 75	O. F. Clapp.
Rochester, N. Y.	2 11	6"	1-2-4	4 00	— .05	Natural	70	1 00	1 10	1"	+ .10	2"	0.00	10 "	0.00	8	1 50	0.00	2 18	E. A. Fisher.
San Antonio*	1 99	6"	1-2-4	4 40	— .18	"	1 50	1 00	75	No	+ .28	2"	0.00	10 "	0.00	8	1 50	0.00	2 10	E. G. Truhart.
San Francisco*	1 89	6"	1-2¼-7	4 86-5 50	— .25	Portland	2.75 to 3.00	70	1.25 to 1.50	No	+ .28	2½"	— .19	No	+ .18	9	2 00	— .03	1 88	E. G Morser.
Scranton	2 20	6"	1-3-7	4 20	— .17	"	1.80 to 2.00	1 00	1 25	1½"	0.00	1½"	+ .19	10 "	0.00	10	1 50	+ .05	2 27	Jos. T. Phillips.
Spokane	2 29	4"	1-3-6	7 65	— .30	"	4 50	70	.95 to 1.00	1½"	0.00	2"	0.00	10 "	0.00	8	1 60-2 00	— .03	1 96	Otto A. Weile
St. Paul	2 55	6"	1-2-4	3 00	0.00	Natural	....	....	....	1"	+ .10	2"	0.00	10 "	0.00	10	1 50-1 75	....	2 65	O. Clausen.
Toledo	1 96	6"	1-2-5	....	0.00	"	....	....	....	1"	+ .10	2"	0.00	5 "	+ .15	10	1 50	+ .05	2 26	Wm. F. Brown.
Toronto	2 75	8"	1-3-6	5 40-6 00	— .24	Portland	2 24	79	1 60	¾"	+ .14	2½"	— .19	10 "	0.00	9	1 62	0.00	2 46	C. L. Fellowes.
Utica	2 35	5"	1-2-5	4 00	+ .07	Natural	85	.70 to 1.00	1 25	1"	+ .10	2"	0 00	10 "	0.00	8	1 50	0.00	2 52	P. L. Schultze.
Washington, D. C.	1 79	6"	1-2-5	3 50	— .07	"	70	40	1 25	1½"	0.00	1½"	+.19	5 "	+ .15	8	1 20	+ .05	2 11	C. R. Hunt.
Winnipeg	1 79	4½"	1-3-6	5 74	— .30	Portland	3.65 to 3.80	1 00	1 10	1½"	0.00	1¼-2"	+.09	..	+ .18	9	1 53-1 80	0.00	1 76	H. N. Ruttan.

The price given in column of price per square yard reduced to Buffalo specifications is obtained by reducing the specifications and prices from the respective cities to Buffalo specifications and prices, assuming that the cost of guarantee for the first 5 years is 3 cents per yard and for the second 5 years is 15 cents per yard. Total, 18 cents per yard.

Average of reported prices is $2.28 per square yard; average of corrected prices is $2.41 per square yard, the price for Buffalo being $2.20 in each case.

*Bituminous rock asphalt. †Cushion.

BLOCK-STONE PAVEMENTS.

Block-stone pavements are forms of the most ancient pavements, the details of which have been adapted to the conditions of modern city traffic.

Examination of the conditions in the great cities which do the best street-work, and which employ the best skill to plan and to execute it, shows that block-stone pavement of all kinds have long been regarded as necessary evils which have only been tolerated because they were improvements on the barbarous cobble-stone pavements which formed the first stepping-stones out of the mud, and because better substitutes were lacking. There have been obvious advantages which have off-set the evident disadvantages, thus inducing a more general use of block-stone than is now necessary.

Block-stone pavements are now only desirable for steep grades, or for those streets of the largest cities where the heaviest traffic exists. There is no such traffic in any city of moderate size.

It has been considered until recent years that blocks of the hardest trap rock, or basalt, or granite were best adapted to endure the class of traffic which required block-stone, and vast sums have been spent in preparing and laying blocks of granite from Massachusetts,

CLERMONT AVENUE, BROOKLYN, N. Y.
Paved about 1880.

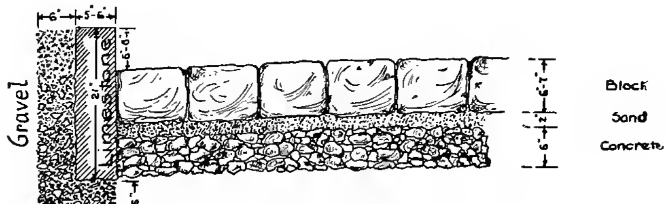
EIGHTH AVENUE, BROOKLYN, N. Y.

OLD COBBLE-STONE PAVEMENTS.

Jan. 1, 1901, New York City (Manhattan) had 227 miles of cobble.
Brooklyn had 300 miles of cobble and defective blocks.

Maine and Vermont, and of diabase trap rock from the Palisades of the Hudson.

Paving blocks formed of these rocks and laid in the usual manner with sand joints, wear in such a way that their tops become rounded and polished, giving a poor foothold for horses, and forming a surface which collects and retains filth, and causes noise, and is injurious to public health and comfort: the hardest and finest-grained rocks giving the worst results, so that the coarser grades of granite have nearly displaced trap rock for paving blocks.



Granite Pavement

Broadway, New York, has very heavy traffic and has been repeatedly paved, from Fifty-eighth street to the Battery, five miles, with various forms of granite and of trap blocks; portions of which have needed relaying after three years' use, and all of which have been dirty and noisy. These conditions are shown to be unnecessary by the fact that during 1900, this block-stone pavement was re-set and used as the foundation for noiseless sheet-asphalt, which can be kept clean, and which is guaranteed to be in perfect condition during and at the end of ten years. This was done from Fifty-eighth street to Fourteenth street, two and a half miles, (and also on sixty other streets in New York,) during 1900, and has been extended to Canal street,

Metropolitan Opera House

BROADWAY, NEW YORK, 1900.
Looking up from the Casino at Thirty-ninth Street.
After paving with sheet-asphalt, in 1900: Trinidad Lake wearing-surface; Bermudez Lake binder-coat.

one and one-fourth miles, during 1901, and in 1902 will be continued one and one-fourth miles to the foot of Broadway at the Battery. Many other cities of the United States have, during the past ten years, preferred to use sheet-asphalt or brick rather than granite blocks, with the result that the total annual expenditure of the cities of the United States for granite block pavements has decreased one-half since 1890.

The ill results obtained from pavements of granite and trap blocks are much less marked when the pavements are formed of blocks of Medina, N. Y., sandstone or Kettle River, Minnesota, sandstone. These sandstones wear flat, do not polish, and approach granite in their resistance to crushing force, as indicated by the following statements of average pounds of crushing force endured per square inch:—

Maine granite, 15,000 to 22,000 pounds; Quincy granite, 19,500 pounds; average of several of the New England granites, 22,000 pounds; Palisades diabase trap, 19,700 pounds; Medina, N. Y., sandstone, on bed, 17,500 pounds; Berea, Ohio, sandstone, 10,250 pounds; Oxford, N. Y., blue stone (sandstone), 13,470 pounds; Kettle River, Minnesota, sandstone (after seasoning), on bed, 12,300 pounds.

Paving blocks of Medina sandstone are used to the largest extent in the cities of Rochester and Buffalo, N. Y., and Cleveland, Columbus and Toledo, Ohio, and are quarried along both sides of the Erie canal in various places from thirty to fifty miles west of Rochester, N. Y. The methods are particularly good in Rochester and in Cleveland, where the best pavements are laid on concrete foundation. At Rochester, the half-inch joints are filled with hot coarse sand and hot

Setting Medina sand-stone blocks on six-inch concrete base covered with one and one-half inches to two inches of sand-cushion.

Filling joints with coarse sand and hot paving cement.

BLOCK STONE PAVEMENT, ROCHESTER, N. Y., 1900.

paving cement. The pavements are built by Edwin A. Fisher, M. Am. Soc. C. E., as city engineer, and the results are the best of which the material is capable, at a cost, in May 1901 of $2.48 per square yard completed including six-inch foundation of Portland cement concrete. At Cleveland, Ohio a similar pavement is built with close joints.

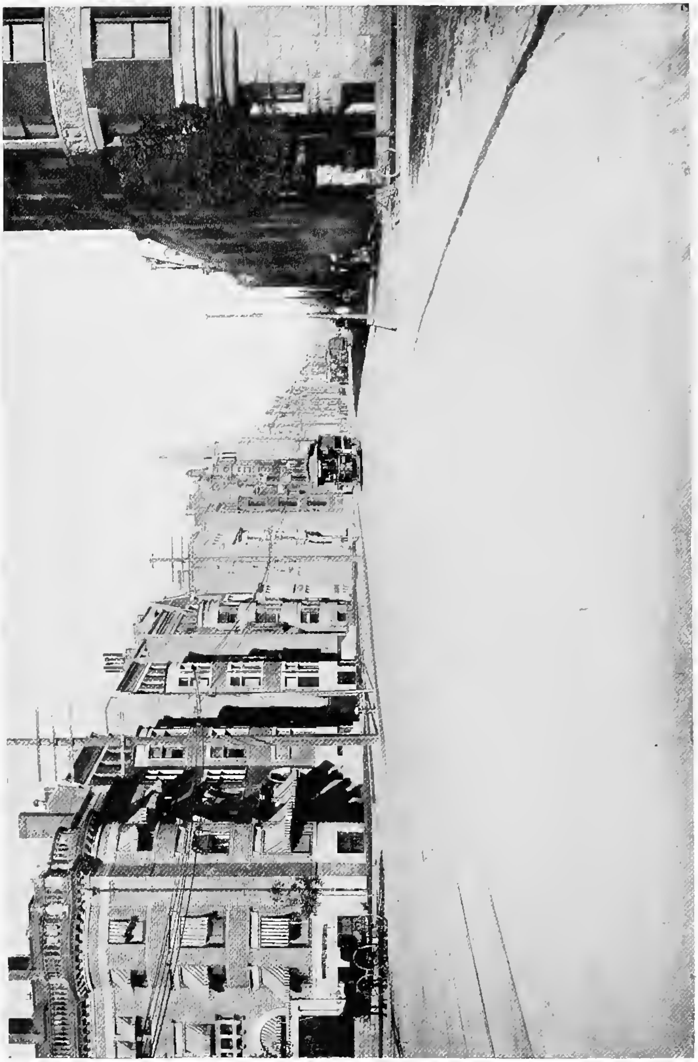
Paving blocks of Kettle River sandstone are used in in Saint Paul and Minneapolis, Minn., and are quarried at Sandstone, Minn., about one hundred miles northeast of Minneapolis. The method of construction and the results are similar to those at Rochester, N. Y., the joints being half an inch wide and being filled with equal parts of Portland cement and sand. The cost at St. Paul in 1900, including six-inch concrete base, was $2.45 per square yard completed.

The following table shows the relative use of several kinds of block-stone pavements in various cities:—

MILEAGE OF BLOCK STONE PAVEMENTS
(on basis of 30 feet width or 17,600 square yards per mile).

CITY.	State.	Year.	Granite.	Diabase Trap.	Sandstone.
Albany	N. Y. ..	1902	28 miles	2 miles	....
Atlanta	Georgia,	1902	52 miles	....	....
Boston.........	Mass. ..	1902	114 miles	....	....
Buffalo........	N. Y. ..	1899	....	....	108 miles
Chicago	Ill.	1890	21 miles	....	....
Cincinnati.....	Ohio...	1902	58 miles	....	....
Cleveland	Ohio...	1900	....	....	121 miles
Columbus	Ohio...	1900	2 miles	....	7 miles
New York:					
Brooklyn....	N. Y. ..	1902	146 miles	1 mile	....
Bronx	N. Y. ..	1902	44 miles	7 miles	....
Manhattan ..	N. Y. ..	1902	192 miles	87 miles	....
Queens	N. Y. ..	1901	29 miles	7 miles	....
Richmond...	N. Y. ..	1901	½ mile	$\frac{1}{10}$ mile	....
Philadelphia ...	Pa.	1902	340 miles	....	....
Richmond.....	Va.....	1902	1 mile*	....	....
Rochester	N. Y. ..	1901	....	....	31 miles
St. Louis	Mo. ...	1902	70 miles	....	....
St. Paul	Minn...	1901	....	....	3 miles
Toledo	Ohio...	1902	....	....	6 miles
Troy	N. Y. ..	1902	26 miles	3 miles	....
Washington....	D. C. ..	1900	28 miles	....	....

* Also 31 miles of "granite spalls."



BEACON STREET, BOSTON, 1901.
Creo-Resinate Wood-block Pavement, laid in September, 1901.

WOOD PAVEMENTS.

Wood-block pavements, as built since 1900, surpass others in freedom from noise, and rank among the best in qualities and in cost.

Of the many forms of wood pavements which have been built, only those need be described in detail which are still in actual construction: brief descriptions being given of the cheaper forms, which are only regarded as temporary expedients, and fuller details being shown of those latest and most improved forms of wooden block pavements which are now ranked with the best class of modern work.

The corduroy roads of a century ago are now best known in the tales of our grandfathers, although there can yet be found, crossing swamps on the line of the old military road which was built in 1812 across the Adirondack wilderness, from the Mohawk valley at Schenectady to Ogdensburg on the St. Lawrence, and to Sackett's Harbor on Lake Ontario, sections of corduroy road, which are still as sound as when laid, having been preserved from decay by the water which has usually covered them, although huge forest trees have meantime grown up in the old and abandoned roadway near at hand.

The plank roads of a half century ago are nearly gone, with the toll-gates which were the objects of their beginning and the cause of their ending; though it is of curious interest that there are still, in 1902, two plank roads leading from the westward into the city of Albany, N. Y., having five toll-gates on ten miles of road; but these relics of old days are of only historic interest, as are the majority of the thirty patented and forgotten forms of wood pavements which had their rise and fall thirty to forty or more years ago, beginning in Boston, Philadelphia and New York about 1840 and culminating from 1860 to 1870, in the "Nicholson block," of which a description is now useless.

ROUND CEDAR BLOCK.

The well-known round white-cedar block pavement came into general use in western cities about 1880, in response to an urgent demand for something quick and cheap which would last until the abutting lots could be sold. This pavement was built in different ways in the various cities, but it probably has its best form as still built in Chicago in 1900. The prepared subgrade of the street is covered with two inches of sand, in which are embedded, across the street at six feet intervals, one-inch by eight-inch pine boards laid flat, as supports for the ends and centers of two-inch hemlock plank laid lengthwise of the street and close together, forming a regular crowned surface.

The cedar blocks are of sound live wood, free from bark, not less than four, nor more than eight inches in diameter and six inches long. These blocks, unseasoned and untreated, are set on end in close contact, and the irregular interstices are rammed full of half-inch to one and one-half inch gravel. The surface is then flooded twice with coal-tar heated to 300° Fh., using two gallons per square yard in all, followed while hot with a three-fourth-inch layer of clean gravel, not exceeding half-inch, which has been screened from that used to fill the spaces.

In 1900, this cost about seventy cents per square yard in Chicago, where there was then about 880 miles (on basis of thirty feet width) of streets thus paved. This being probably somewhat more than the total similar mileage in all of the other cities using this form of pavement, the relative amounts being in about the following order: viz., Detroit, Superior, Duluth, Milwaukee, Minneapolis and Toronto.

It usually needs renewal in six years and becomes impassable in nine years, though the results are sometimes much better than this.

Cypress blocks were similarly used in Omaha, Des Moines and Kansas City, and failed in two to four years.

BLOCKS ON SIX-INCH CONCRETE BASE.

Hexagonal blocks of mesquite, 5″ deep and 4″ to 8″ diameter have been laid at San Antonia, Texas, at cost of $2.80 per square yard, including the six-inch base.

Tamarack-blocks, 3″ by 5″ by 6″ have been laid in Montreal and coated with hot coal-tar and gravel.

Redwood blocks, 4″ by 6″ by 6″ seasoned, and boiled in asphalt, have been laid in San Francisco and Oakland, California.

Yellow pine blocks, 4″ by 6″ by 6″ to 10″ creosoted with twelve pounds per cubic foot, were laid in Galveston, Texas, in 1895–8.

Creosoted or "treated" blocks on concrete base are recommended for fifteen miles of streets by the board of local improvement of Chicago during 1902..

The late Ex-President Harrison's Residence.

NORTH DELAWARE STREET, INDIANAPOLIS, IND., 1901.

Kreodone-creosote Wood-block Pavement.

Washington cedar blocks, sterilized and creosoted with three to four pounds of creosote per cubic foot, were laid on about four miles of Indianapolis streets in 1896, and some are in good condition in 1901. Some of the wooden pavements built in Indianapolis about that time have swollen and heaved badly.

Oregon red cedar and southern yellow-pine heart-wood blocks, 4″ by 4″ by 9″ creosoted with ten pounds per cubic foot, were laid in 1899 in Indianapolis at a cost of $2.10 to $2.50 per square yard, including base and five years guarantee: the joints being filled with paving cement of nine parts coal-tar to one part asphalt, and the surface being covered with half-inch screenings of crushed granite. This is a much more costly pavement than the others which have been described, and is of a high class, as are the later improved kinds described on page 74.

In Paris, pine blocks of several forms, creosoted with eight to ten pounds of creosote oil per cubic foot, form the greater part of the ninety miles (thirty feet width) of wood-paved streets. Wood is preferred as being less slippery and less noisy than compressed rock-asphalt, and that it is satisfactory in its other qualities is evidenced by the fact that the amount of wood pavement in Paris is increased every year. Including the six-inch concrete base in both cases, the cost complete is about the same as for rock-asphalt, viz., $3.10 per square yard.

AUSTRALIAN HARD-WOOD PAVEMENTS.

These are the most costly of any of the various wooden-block pavements and, therefore, have not been laid to any extent in the cities of the United States.

They have, however, been largely used, and with good effect, in London, which has wood pavements of many kinds to the extent of about 240 miles, computed on a basis of thirty feet width.

The city of Sidney, New South Wales, has many miles of wood-paved streets, upon which Australian hard woods have been used with most remarkable results, which would be incredible if not substantiated by the statements of W. A. Smith, M. Inst. C. E., and also by the report of R. W. Richard, Asso. M. Inst. C. E., the city surveyor of Sidney, and engineer in charge of Sidney pavements. Queen street, which has an estimated daily traffic of 25,000 tons, was thus paved, and the blocks after eight years use, showed a greatest observable wear of one-sixteenth of an inch and were otherwise in almost as good a state in 1893 as when laid. The original cost was $3.05 per square yard, exclusive of foundations, with an annual cost of two cents per square yard for maintenance and for daily sanding.

The details of their construction in Sidney are as follows:

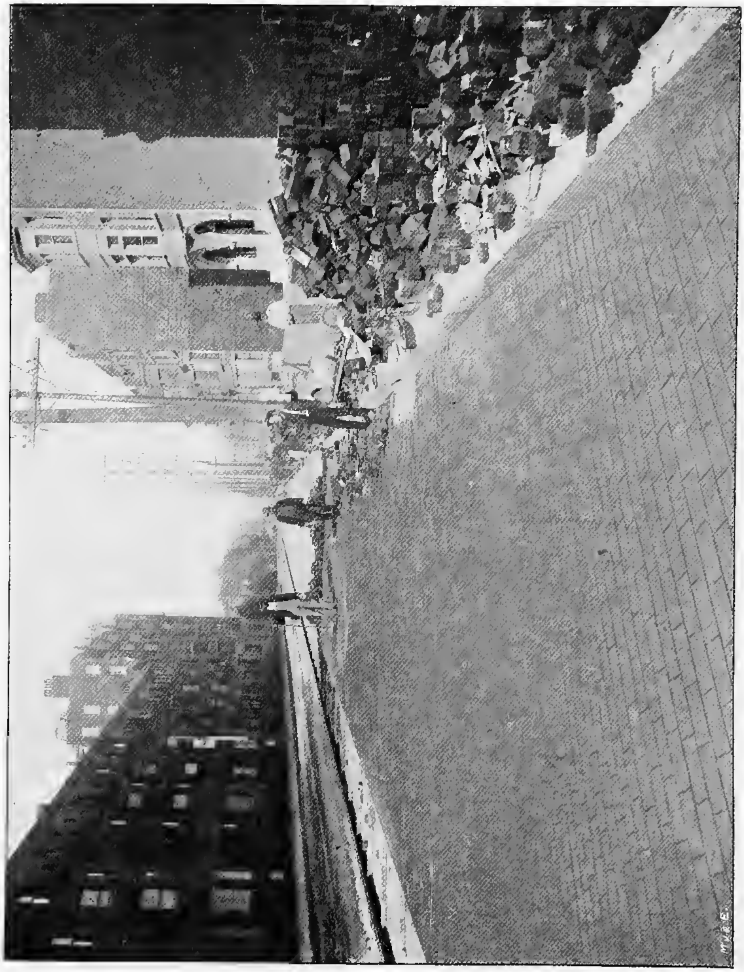
The foundation, or base, was a layer of one-to-seven concrete, formed with a floated smooth surface, having a convexity from one in forty to one in eighty, and allowed to set for seven days before use.

This concrete base was six inches thick on solid ground and nine inches thick on uncertain ground.

The pavement which gave the best result was formed with seasoned heart-wood blocks of tallow-wood, black-butt, and blue gum, red gum, jarrah or karri, each kind being laid separately. Each block was formed by cutting a three-inch by nine-inch plank into pieces six inches long, and these blocks were then painted with, or dipped in, hot coal-tar and hot wood-preserving oil, and stacked for four hours before being set in the work. The blocks were set on end with the fibre vertical, forming three-inch rows across the street from curb to curb, each block breaking joints two inches with blocks in the next row.

To provide for the expansion of the blocks when wet, expansion-joints were formed along each side of the pavement; these joints being two inches wide between the curb and the gutter-course, and an additional one-inch joint between the gutter-courses, which were formed of blocks set in rows running lengthwise of the street. Curbs, eighteen inches deep, were needed to resist the thrust which moved twelve-inch curbs. Better results were reached when these expansion joints were filled with mastic than when filled with sand or with clay puddle. These widths of joint were used on pavements sixty-four feet wide and gave good results.

The best results were obtained when the blocks were forced close together on grades up to one in twenty and with one-quarter-inch joints on steeper



BEACON STREET, BOSTON, 1901.
Creo-Resinate Wood-block Pavement in progress in August, 1901.

grades up to one in thirteen, or eight per cent. After completing sixty lineal feet of roadway, the surface of the pavement was swept with hot coal-tar and sprinkled with hot sand, and again swept with hot tar until the spaces were thoroughly flushed with the plastic paste.

As to the durability of these hard-wood blocks as compared with cubical blocks of blue-stone, Mr. Richard states that the blue-stone blocks have shown a wear of one inch per year, while the hard-wood blocks, laid as described and subjected to similar traffic, have shown a wear of one-fiftieth ($\frac{1}{50}$) inch per year.

Where the joints have been filled with hydraulic cement, the results were not as satisfactory as where blocks were laid with close joints, but with the construction described, these wood-block pavements are free from the various faults of our cedar blocks and are expected to have a minimum life of sixteen years, equaling asphalt.

In Melbourne, similar pavement is estimated to last fourteen years. Either of these improved methods or the more crude ones generally used in this country are costly. The final expense of our cheap construction being twice as great as for asphalt or for granite blocks, and probably much greater than if white oak or some similar hard wood were used.

AMERICAN WOOD PAVEMENTS OF THE LATEST TYPE.

The valuable qualities of the highest grade of treated wood-block pavements have been generally recognized especially their freedom from noise; but their extensive use in the cities of the United States has been deferred by distrust based upon former failures and by the excessive cost. The cities seem to have awaited the development of some process of treatment of native woods which should be less costly than the Australian hardwoods just described, and more satisfactory in various ways than the former well-known American methods.

The creosote as ordinarily used is an effective preservative in itself, but it tends to form an emulsion with water, and also to evaporate half to three-fourths on exposure to the sun and the weather.

To avoid these defects has been the object of two recent modifications of the treatment: the one called "kreodone-creosote," and the other "creo-resinate."

Concrete base In progress. Ten-ton roller. Completed pavement.

MERIDIAN STREET, INDIANAPOLIS, 1902.
Kreodone-Creosote Wood-block Pavement in progress in March, 1902.

KREODONE-CREOSOTE PROCESS.

This consists in impregnating the seasoned selected blocks under pressure with ten pounds per cubic foot of an oil derived from creosote oil, possessing the original preservative properties with a longer endurance, and also having the effect of forming a varnish-like film or coating on the outer surface of the wood. protecting it from the elements.

The seasoned blocks are sterilized by subjecting them to dry heat of 240° Fh., for eight hours. The kreodone-oil is then forced into the fibres of the wood, under a pressure of seventy pounds per square inch, maintained for two to three hours, or until twelve pounds have been absorbed by each cubic foot of the wood.

In some cases the blocks are laid with the courses running diagonally across the street. The cost in Indianapolis for blocks four inches deep, has been $2.50 to $2.70 per square yard of completed pavement, including concrete base, and also including nine years' guarantee and maintenance.

The cost of the Chicago pavement on Michigan avenue, in front of the Auditorium hotel, for blocks five inches deep, exclusive of the concrete base, and including surety company guarantee for five years, was $1.90 per square yard.

This Chicago pavement and that on North Delaware street in Indianapolis, were both laid in 1901, and will furnish conspicuous examples by which may be observed the peculiar qualities of pavements treated with kreodone-oil.

CREO-RESINATE PROCESS.

A pavement treated by this process has become known during 1900 and 1901 by having been laid on conspicuous streets in Boston, on Tremont street in front of the Parker House and on Harvard Bridge and on Beacon street, and in Springfield, Mass., and in New Rochelle, N. Y., and on Holliday street, Baltimore, Md., where these pavements have been much commended.

B. T. Wheeler, superintendent of streets of Boston, states that the creo-resinate pavement seems the most

Asphalt. Wood.

TREMONT STREET, BOSTON, 1900.

Creo-Resinate Wood-blocks, laid in 1900.

satisfactory piece of wood-paving in Boston, and that it is guaranteed to be kept in such condition for ten years. As there used, the pavement is noiseless, is free from dust, is not slippery when wet, when laid on three per cent grade with the grooved joint shown on page 29, can be taken up and re-laid readily, does not absorb moisture, and promises to be durable, though this can only be assured by the test of time.

The special features of the creo-resinate process are the preliminary treatment in dry heat to kill the germs of decay, and the mixing with the creosote of fifty per cent of melted rosin which is forced into the fibres with the creosote, where it solidifies and seals the pores of the wood and prevents the evaporation of the creosote or its displacement by water, which can find no entrance, so that the pavement does not swell and heave when wet.

The blocks are of Georgia long-leaf yellow-pine heart-wood 4″ by 8″ by 4″ deep and are treated in an air-tight cylinder by dry heat for five hours, during which time the temperature and pressure are gradually raised to 285° Fh., and to ninety pounds per square inch, when both are gradually lowered and a vacuum is produced, followed by hot creo-resinate mixture, afterwards forced in by hydraulic pressure of 200 pounds per square inch, which is maintained until twenty-one to twenty-two pounds of the mixture has been absorbed by each cubic foot of the wood.

This is followed, in another cylinder, by hot milk-of-lime under the same pressure, in order to fix and set the creosote, so that the blocks, when ready for use, present a peculiarly solid appearance.

The blocks are then laid, with the grain vertical, upon a one-inch cushion of screened sand, covering a six-inch concrete base; the blocks are driven tightly together at every sixth row and are rolled with a five-ton steam-roller until a firm, uniform and unyielding surface is made, when the whole is covered temporarily with one-quarter inch of clean screened sand.

COST.

The cost of this pavement, complete, including a surety company ten-year guarantee, for blocks four inches deep on concrete six inches deep, varies with the local conditions from $3.10 to $3.50 per square yard.

Main street, Dayton Ohio, paved in 1892.

Street in St. Louis, paved in 1901.

BRICK PAVEMENTS IN 1901.

VITRIFIED BRICK PAVEMENTS.

THEIR USE IN THE UNITED STATES.

During the past seventeen years there has been a steadily increasing use of vitrified brick for the pavements of the streets of cities and towns in the United States, especially of those of moderate size—that is, of 100,000 inhabitants and less: the larger places welcoming brick as a competitor with sheet asphalt, and as affording another means of escape from the intolerable noise and dirt resulting from block-stone pavements and from the temporary and unsanitary features of cedar blocks, while the smaller western towns, with characteristic enterprise, have built miles of brick pavements to displace the natural mud. The total length of brick-paved streets in the United States in February, 1902, is estimated by Wm. S. Crandall, editor of The Municipal Journal, at about 1300 miles.

The following table is reprinted from the first edition of "City Roads and Pavements," and shows the modes, costs and results in sixty-five cities in 1894:

Brick at entrance to Union Station, laid in 1893.
(Stone-block pavement in foreground).

Alley paved with brick in 1894.

BRICK PAVEMENTS, ST. LOUIS, 1901.

Summary of Reports of Modes of Construction, Cost and Results of Vitrified Brick Pavements.

City and State.	Miles in use June, 1894.	Cost per Square Yard of "Best Work" on the Foundation here indicated.			Filling of Joints.	Reported Results.
		Six inches Concrete.	Flat Brick or Gravel.	Broken Stone or Gravel.		
Atlanta, Ga.	1.1	$2.19			Paving tar.	Satisfactory.
Atchison, Kan.	2.75		$1.75		Sand.	Excellent.
Alton, Ill.	1		2.16		Sand.	
Alleghany, Pa.	2	1.60			Paving tar.	Fair.
Bellaire, Ohio				$0.61		
Binghamton, N. Y.	0.25	2.40			Cement grout.	Fair.
Bloomington, Ill.	6		2.00		Sand.	Good.
Buffalo, N. Y.	3.33	2.75			Cement grout.	Fair.
Burlington, Ia.	7.50		1.60		Sand.	Gratifying.
Cedar Rapids, Ia.	2		1.35		Sand.	Fair.
Charleston, W. Va.				1.15	Sand.	
Chicago, Ill.	1	2.30			Paving tar.	Satisfactory.
Cincinnati, Ohio	15	2.50			Paving tar.	Fair.
Clinton, Ia.	10			1.45	Sand.	Good.
Columbus, Ohio	30	2.00			Paving tar.	Good.
Connellsville, Pa.	2			2.49	Sand.	Excellent.
Council Bluffs, Ia.	5		1.50		Sand.	Good.
Davenport, Ia.	6		1.60		Sand.	Good.
Dayton, Ohio	6.4	2.30			Cement grout.	Good.
Decatur, Ill.	15		1.75		Sand.	Good.
Detroit, Mich.	9.6	2.50			Paving tar.	Fair.
Des Moines, Ia.	10	1.70			Paving tar.	Good.
Dubuque, Ia.	1.5	1.69			Sand.	Satisfactory.
Dunkirk, N. Y.	2.5	2.10		1.87	Cement grout.	Good.
Evansville, Ind.	4.5	1.70			Sand.	
Findlay, Ohio	4			1.75	Paving tar.	Satisfactory.
Fort Wayne, Ind.	2	1.63			Cement grout.	Good.
Galesburg, Ill.	12		1.80		Sand.	Good.
Hannibal, Mo.	1.5		2.05		Sand.	Perfly. satisfy.
Hartford, Conn.	0.12	4.00			Cement grout.	Good.
Indianapolis, Ind.	8.7	2.35			Paving tar.	Good.
Jacksonville, Ill.	9			1.40	Sand.	Good.
Kansas City, Mo.	10.25	2.00				Fair.
Kenosha, Wis.	1			1.55	Sand.	Good.
Keokuk, Ia.	1.25		1.55		Sand.	Good.
Lafayette, Ind.	2.50		1.80		Sand.	Good.
Lancaster, Pa.	0.10	1.80				Good.
Lexington, Ky.	6	2.25			Paving tar.	Good.
Lincoln, Neb.	15		1.75		Cement grout.	Good.
Lockport, N. Y.	10	2.09			Cement grout.	Excellent.
Louisville, Ky.	10	1.50				Good.
Massillon, Ohio	9			1.40	Sand.	Good.
Memphis, Tenn.	2.25	2.65			Paving tar.	Entirely satis.
Olean, N. Y.	1.50	2.00			Cement grout.	Good
Omaha, Neb.	10.25	1.87			Sand.	Moder'tely fair
Ottawa, Ill.	2.25		1.40		Sand.	Good.
Peoria, Ill.	7	1.75			Sand.	Fair.
Philadelphia, Pa.	20	2.05				Good.
Providence, R. I.	1	3.00			Paving tar.	
Quincy, Ill.	6			1.80	Sand.	Good.
Rochester, N. Y.	3.14	2.30			Paving tar.	Good.
Rockford, Ill.	1.82		1.75	1.37	Sand.	Good.
Rock Island, Ill.	7		1.62	1.33	Sand.	Satisfactory.
St. Paul, Minn.	0.34		2.40		Sand.	Indifferent.
Scranton, Pa.	0.10	2.33			Cement grout.	Good.
Springfield, Ill.	5.38			1.35	Sand.	Good.
Steubenville, Ohio.	10			1.00	Sand.	Good.
Syracuse, N. Y.	5	2.15			Cement or tar.	Good.
Terre Haute, Ind.	1			2.25	Cement grout.	
Toledo, Ohio	16.33			1.05	Sand.	Good.
Troy, N. Y.	1	2.50			Cement grout.	Good.
Washington, D. C.	0.25	2.05			Cement grout.	Good.
Watertown, N. Y.	0.12	2.46			Sand.	Good.
Wheeling, W. Va.	2			1.35	Paving tar.	
Wilmington, Del.	3			2.15	Cement grout.	Satisfactory.
Average of prices.		$2.19	$1.75	$1.52		

EXTENT OF ITS USE.

Two to three hundred such cities and towns, as well as all of the larger cities, especially Philadelphia, have laid more or less vitrified brick pavement, and its use is constantly extending, as is shown by the accompanying table on page 130, compiled by Willis Fletcher Brown, city engineer of Toledo, Ohio, showing the miles of streets paved with brick and with sheet asphalt in thirty cities.

This table also shows the relative estimation in which brick is held as compared with sheet asphalt in cities where both have been used for a period long enough for opinion to be formed.

REACTION AGAINST USE OF BRICKS.

There has undoubtedly been a reaction in the popular desire for brick pavements in some of these cities, where people have learned to know what good pavements are and where brick pavement has been brought into close comparison with sheet asphalt, and with the best grades of creosoted wood-block pavements in the western cities, and more recently by comparison with bituminous macadam or bitulithic pavement, in a few of the cities of the east.

The excessive and peculiar roaring noise produced by the passage of light wagons over some brick pavements is objectionable on residence streets, and on some streets having heavy traffic there have been poor results as to durability. Much discredit has also been thrown upon the use of vitrified brick by the careless and ill-judged manner in which many manufacturers have sent out irregularly and imperfectly burned brick. These have been laid by incompetent contractors, under inexperienced city officials, and have thus caused the needless failure of many pavements, thus stopping further extensions and preventing other cities from using brick at all, to the great gain of the sheet-asphalt companies, and with the effect of encouraging the introduction of bituminous macadam, creo-resinate wood blocks and other high-grade pavements which are free from these defects and which have not yet had time to develop other defects which may be peculiar to themselves.

REGION OF PRODUCTION.

The production of vitrified paving brick in 1894 was in a measure restricted within two regions of Pennsylvania and Ohio on the southwest and Indiana and Illinois on the west, which produced the special quality of material for forming paving bricks, which differ entirely from ordinary building bricks in both their material and mode of manufacture and in their qualities; the name being a misleading one, as they are not brick but tile, and are not actually vitrified, but are fused.

There are now a number of places outside these limits where paving bricks are produced in large quantities, one of the large plants being on the Hudson river at Catskill, from which have been furnished bricks for pavements in 112 cities and towns, nine-tenths of which are in seven of the eastern states, and the rest are in six of the southern states. The material of these bricks is low-grade iron ore, shale and clay, which are ground to a powder and mixed in proper proportions and formed into repressed bevelled-edge vitrified paving bricks and blocks, which compare well with others, and which have been used for most of the brick pavement in Albany, N. Y., with good results.

Other well-known kinds of high-grade paving materials are the Mack bricks and blocks, made at very large works, located at New Cumberland, W. Va., fifty-six miles west of Pittsburg, Pa. These have been used for pavements in 100 cities and towns, two-thirds of which are in five of the eastern states, the rest being in three of the middle western states and four of the southern states.

The materials are silica, alumina and iron, forming fire-clay, which is ground to powder and mixed with water in proper proportions and moulded into bevelled-edge vitrified paving bricks and blocks.

Streets of Philadelphia, equal to over sixty miles length of thirty feet width, have been paved with these blocks, and it is stated by Wm. H. Brooks, chief of bureau of highways of Philadelphia, that some streets thus paved for over ten years have required no repairs and are now in good condition.

CHARACTERISTICS.

The material for moulding any paving brick must be of a peculiar character which will not melt and flow when exposed to an intense heat for a number of days, but will gradually fuse and form vitreous combinations throughout, while still retaining its form.

The resulting brick must be a uniform block of dense texture, in which the original stratification and granulation of the clay has been wholly lost by fusion which has stopped just short of melting the clay and forming glass.

The clay while fusing must shrink equally throughout, thus causing the brick to be without any laminations or any exterior vitrified crust differing from the

Highway Division, Maryland Geological Survey, 1902.

ABRASION AND IMPACT TEST OF PAVING-BRICKS.

Standard Machine of 1900.

interior. Such a brick will be incapable of absorbing any considerable amount of water, and will hence be unaffected by frost, and if formed of the best material properly treated will be tough, to withstand the blows of horses' toe-calks; hard to resist the abrasion of wheels, and strong to carry heavy loads: these being in the order of effectiveness of the destructive forces to be met.

There is now little difficulty, with rigid inspection, of getting brick which will uniformly possess these qualities.

QUALITIES OF PAVING BRICK.

If the brick are uniform in character and are perfectly formed of proper material which is thoroughly fuzed, they will be harder than glass and nearly as hard as quartz (being 6.5 on Mohs' scale), and will be tough enough to endure traffic. These qualities will be best determined by the following described test:

ABRASION AND IMPACT TEST.

The standard test revised and adopted by the National Brick Manufacturers Association in 1900, provides for the use of a machine having a rattling chamber twenty-eight inches in diameter and twenty inches in length, formed of two steel heads and fourteen steel staves set one-fourth inch apart to allow the escape of the chips and dust. This machine must be set to run uniformly at about thirty revolutions per minute for about sixty minutes, or for 1,800 revolutions by actual count of a cyclometer. Each separate charge of bricks to be tested must consist of bricks of one kind, which must be perfectly clean and dry, and free from moisture: twelve paving bricks or nine paving blocks (so called because larger), are accurately weighed and constitute a charge, together with 300 pounds of cast iron in the form of blocks with rounded edges and corners: one-fourth in weight to be two and one-half inches square on end and four and one-half inches long, and three-fourths to be one and one-half-inch cubes.

After 1800 revolutions, made as stated, the loss is determined by again weighing the brick: the limit of loss which is allowed varies in different specifications: the St. Louis specifications reject bricks when the tests show a loss of over thirty per cent of the original weight: Columbus, Ohio, puts the limit at twenty-seven and one-half per cent: many lots of bricks tested will lose less than twenty per cent.

Such brick must be practically without pores, for a brick which can absorb water equal to more than two per cent of its dry weight, will probably fail to endure the rattler test.

The absorption test is, therefore, not a useful one, and may mislead, and may safely be omitted.

The tests by abrasion, and for absorption, and for crushing strength, are the most important of the numerous tests which are sometimes specified, and of the total value of all the tests, the abrasion test is variously considered as varying from thirty per cent to seventy-five per cent of the whole.

EXAMINATION OF BRICKS IN USE.

The best and most useful test can, however, be made by visiting places where brick pavements have been in use for several years, and by examining the actual results of traffic upon well-known and standard makes of brick.

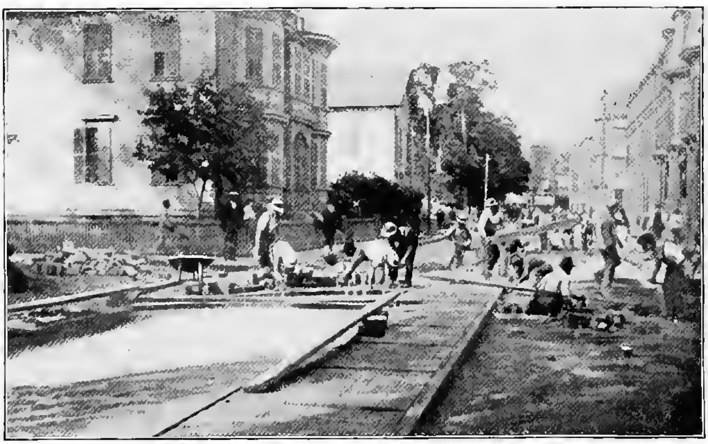
For instance, Columbus, Ohio, has some eighty miles of brick pavement, varying in age from one to twelve years, in which twenty-six kinds of paving bricks and blocks have been used, with various kinds of fillers in the joints. Dayton, Ohio, has twelve miles of brick pavement, in which fourteen kinds of bricks and blocks have been used.

Des Moines, Iowa, and Terre Haute, Indiana, have also large mileage, composed of great varieties of materials, as have also Cleveland and Toledo, Ohio, Louisville, Ky., and Detroit, Michigan.

A few days spent in such examination of pavements in actual use will make experiments unnecessary, and will enable the engineer who is planning new work to avoid poor bricks and to specify those kinds which can be depended upon to give good results.

This method of natural selection is gradually forcing the poor grades of brick out of the market.

Mixing and placing concrete base.



Placing brick on sand cushion.

BRICK PAVEMENT, PROSPECT STREET, CAMBRIDGE, MASS., 1898.

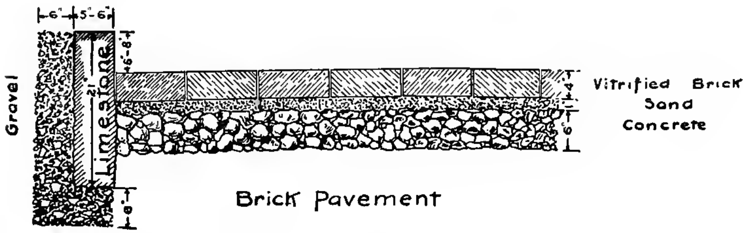
Rolling with two and one-half ton roller.

Spreading Portland cement grout filler.

BRICK PAVEMENT, PROSPECT STREET, CAMBRIDGE, MASS., 1898.

VARIOUS STYLES OF CONSTRUCTION.

The table on page 84 is reproduced from the first edition as showing the actual practice in 1894 in the sixty-two cities there named, of which thirty-four then used one course of brick set on edge on a six-inch concrete base with a sand-cushion of one inch.



The table on page 100 shows a more general use of a concrete base in 1900 and 1901, and this is to be expected as showing a higher standard of work obtained at less cost. Broken stone forms a good base, especially where it is covered with a layer of sand, with a course of second quality of brick, laid flat, as foundation for the surface-course of brick set on edge.

Two courses of brick on sand have been used for seventeen miles of pavement in Topeka, Kansas, some of which has been in use for twelve years, and all of which is in fine condition in 1902. It is there preferred as being less noisy than when laid upon a concrete base, and being made from local brick has cost $1.25, or less, per square yard.

A concrete base, for which details are given on page 42, is, however, usually well worth the extra cost, and should be used in preference to any cheaper substitute; especially for a city which has been educated to a correct idea of what constitutes a good pavement.

MODE OF CONSTRUCTION.

The earth roadbed being sub-drained and rolled hard, as described for other pavements, should be formed with a regular crown of about one one-hundredth the width between curbs: the best amount of crown is an important matter discussed on page 30, and the following table is given to show the practice in 1900 in twenty-seven cities having experience with brick pavements:

ACTUAL "CROWN" OF BRICK PAVEMENTS AS BUILT IN 1900.

CITY.	STATE.	Inches per 30 ft. width bet. curbs	CITY.	STATE.	Inches per 30 ft. width bet. curbs.	CITY.	STATE.	Inches per 30 ft width bet curbs.
Albany	N. Y.	5	Fort Wayne	Mich	4	New Orleans	La.	5
Atlanta	Ga.	5	Grand Rapids	Mich	6	Peoria	Ill.	6
Binghamton	N. Y.	5	Harrisburg	Penn	5	Sandusky	Ohio	6
Buffalo	N. Y.	5	Houston	Texas	6	Scranton	Penn	5
Columbus	Ohio	6	Jackson	Mich	4	Springfield	Mass	3½ to 7
Dayton	Ohio	4½	Joliet	Ill.	5	St. Paul	Minn	5¼
Detroit	Mich	4½	Mansfield	Ohio	6	Terre Haute	Ind.	6
Elmira	N. Y.	4¼	Meridan	Conn	6	Toronto	Ont	7
Erie	Penn	6	Milwaukie	Wis	8½	Troy	N. Y.	4

BASE FOR BRICK PAVEMENT.

This may be formed in either of the several ways mentioned on page 94, but should generally be four or six inches of concrete, as detailed on pages 42 to 56.

SAND CUSHION.

When ready to set the brick, the sand cushion is formed by spreading screened moist sand over the concrete or other base: this is spread uniformly to the required depth of one and one-half to two and one-half inches, and smoothed and brought to the proper crown by wooden templates, traveling on wheels or shoes and resting on the top of the curbs on either side. Upon the true surface thus formed upon the sand, the brick are set on edge, the workmen standing only upon the brick already laid, and placing the bricks in front of them in regular lines across the street; the brick in each course breaking joints with those in the next courses. The bricks are then rammed with a seventy-five pound rammer and rolled with a two and one-half-ton or a five-ton steam roller and settled firmly into the sand-bed. If the surface is then sprinkled and examined, soft brick can be detected and picked-out as being those which remain wet after the hard bricks have dried.

JOINT FILLERS.

No filler has yet been found that is perfect, and there are wide differences of opinion as to the best.

Sand filler is cheap and allows the brick to be readily taken up and relaid, but it also allows the edges and corners of the bricks to chip and become rounded, and permits the bricks to settle at soft spots of subgrade.

Portland Cement Grout of equal parts by bulk, of loose cement and fine sand, if properly made and applied, is better, and there are patented mixtures which are combinations of iron-slag and cement ground together, and which are equally good or better. Grout is irregular and worthless, unless the sand used is so fine as to remain in suspension, and such sand is not easy to obtain: grout should be poured into place, but is sometimes flushed broadly over the surface and swept into the joints. Grout makes it difficult to take up and relay the brick, but it can, if properly made and applied, perfectly protect their edges and corners and thus preserve a smooth surface, which is most desirable.

For some reason which is not clear, the pavements with cement grout joints seem to be the most noisy.

Paving Cement makes an elastic joint which in some cases is best, although it costs more than grout. The usual composition consists of 100 parts by weight of No. 4 coal-tar, three parts residuum oil and twenty parts refined asphalt, kept and used at a temperature of 300° Fh., meantime carefully avoiding over-heating it. This hot mixture should be poured into the joints from a spout, or it may be poured upon the surface and swept in with steel wire brooms: a thin coating of sand should be at once spread over the pavement, and this will mix with the surplus pitch while still hot so that traffic will soon grind the whole from the surface and leave the bricks clean.

Expansion.—The expansion of brick pavements during and after periods of extreme heat has been a frequent source of trouble, and many pavements have been thus heaved and broken; in some cases by a quiet raising of the brick pavement until the arch thus formed was broken by its own weight or by traffic, as occurred at Niagara Falls in July, 1897, and at Glens Falls in August, 1901: in other cases by sudden ruptures or explosions, as at Kansas City in July, 1901, where this occurred on seven streets and brick were thrown up a foot or more. In nearly every case this peculiar result has occurred where the brick have been laid with cement joints, and where the cross-expansion has been prevented by rigid curbs; or at the apex of grades from both ways, or at the top of a steep incline where the resulants of longitudinal expansion have been concentrated at one place.

Expansion-joints of one inch of coal-tar, or mastic, or bitumen or sand have been formed along the curbs on both sides of the street and across the pavements from curb to curb at intervals of fifty feet: one city in central New York took special precautions of this kind and yet has had more or less trouble every year. Other cities have taken no precautions and have no trouble. It remains to find a preventive.

BRICK PAVEMENT FOR STEEP GRADES.

Brick pavements are often used successfully on grades which are considered to be too steep for smooth asphalt, which may afford no foothold, or for macadam, which may be gullied by heavy rainfalls. It is often difficult to decide what pavement to use in such cases, and equally difficult to select from the various forms of vitrified bricks and the different ways of laying them, in order to secure the best results on steep slopes.

The following table is given of the steepest grades of brick pavements, in actual use in 1900, in the cities named: the fact that such steep grades are in use, may not be taken as a reason for imitation, but may furnish conclusive reasons for avoidance.

MAXIMUM GRADES OF BRICK PAVEMENTS—1900.

CITY.	State.	Grade in feet per 100 feet.	CITY.	State.	Grade in feet per 100 feet.
Albany	N. Y.	9.3	Nashville	Tenn	7
Baltimore	Md	15	Parkersburg	W. Va.	15
Columbus	Ohio	9	Peoria	Ill.	8.4
Des Moines	Iowa	11	Philadelphia	Penn	6
Erie	Penn	7	St. Joseph	Mo	10
Joliet	Ill.	6	Toledo	Ohio	5.6
Mansfield	Ohio	8	Troy	N. Y.	7
Milwaukee	Wis	8	Wheeling	W. Va.	8

Cost.—The average cost of construction of brick pavement on concrete complete in 1894, not including curbing and extras, as shown by the table on page 84, was $2.21 per square yard, varying from $1.56 at Alleghany, Pa., to $3.00 at Providence, R. I.

In 1900, the cost is materially less, and the prices of several are given as a basis, being obtained from the "Engineering News" and the "Engineering Record," and from direct advices.

On April 10, 1900, at Chillicothe, Ohio, offers were made by six bidders for pavement to be formed of either of seven different kinds of first-class paving bricks, using either of four different kinds of filler in the joints and naming a price for each; six inches of concrete forming the foundation in each case. For the concrete base the prices ranged from twenty-eight to thirty-four cents, with an average of thirty-one cents per square yard.

For the bricks laid in place, the prices ranged from seventy-seven to eighty-eight cents with an average of eighty-four cents per square yard.

For the fillers, the prices per square yard ranged from an average of nine cents for cement to an average of sixteen cents for "No. 6 filler;" fifteen cents was bid and accepted for "Murphy grout," a patented mixture of powdered iron-slag and cement, which was used.

For the complete pavement (not including excavation or curbs) the prices ranged from $1.24 to $1.38, with an average of $1.33 per square yard.

On May 18, 1900, at Kewanee, Illinois, four bids were made for vitrified brick pavement on six inches of concrete for which the price for base, pavement and filler complete in place, ranged from $1.42 to $1.47, with an average of $1.45 per square yard.

These and other prices are given in the table on page 100, in each case giving not only the minimum price, at which the work was done in each case, but

Prices for Brick Pavement, Including Base and Filler Only.

Date.	Place.	Base.					Guarantee.	No. of Bids.	Price per Sq. Yd.		
		Concrete.	Stone.	Gravel.	Brick, flat.	Sand.			Max.	Aver.	Min.
Mar. 7, 1901	Alexandria, La.	6 in.	......	......	......	2 in.	......	2	$2.15	$2.14	$2.14
Mar. 16, 1901	Annapolis, Md.	5 in.	......	......	......	1 in.	......	15	2.31	2.09	1.92
Sept. 10, 1900	Atchison, Kan.	......	......	......	......	3 in.	......	4	.88	.86	.84
Dec. 5, 1900	Birmingham, Ala.	5 in.	......	......	......	1 in.	......	5	1.92	1.80	1.67
Apr. 10, 1900	Chillicothe, Ohio	6 in.	......	......	......	1 in.	......	36	1.38	1.33	1.24
Jan. —, 1899	Columbus, Ohio	6 in.	......	......	......	1½ in.	5 yrs.	....	......	......	1.20
Aug. 6, 1900	Council Bluffs, Iowa	6 in	......	......	......	1 in.	......	7	1.90	1.65	1.02
Aug. 6, 1900	Council Bluffs, Iowa	......	......	......	....	6 in.	......	2	1.52	1.47	1.42
Aug. 6, 1900	Council Bluffs, Iowa	......	......	......	brick.	1 in.	......	9	1.82	1.70	1.43
Apr. 12, 1901	Des Moines, Iowa	6 in.	......	......	......	1 in.	5 yrs.	5	1.70	1.52	1.42
Apr. 12, 1901	Des Moines, Iowa	......	8 in.	......	......	1 in.	5 yrs.	5	1.70	1.55	1.46
Mar 23, 1901	Des Moines, Iowa	6 in.	......	......	......	1 in.	5 yrs.	....	......	......	1.62
Jan. —, 1899	Findlay, Ohio	......	8 in.	......	......	2 in.	5 yrs.	....	......	......	1.00
Aug. 16, 1900	Findlay, Ohio	......	8 in.	......	......	2 in.	5 yrs.	4	1.33	1.24	1.20
Mar. 5, 1901	Garrett, Ind.	......	......	8 in.	......	......	......	15	1.39	1.22	1.00
May 18, 1900	Kewanee, Ill	6 in.	......	......	......	1 in.	......	4	1.47	1.45	1.42
June —, 1900	Rochester, N. Y.	6 in.	......	......	......	1 in.	......	....	2.43	2.04	1.63
Jan. —, 1899	St. Joseph, Mo.	......	......	....	brick on cinders.	2 in.	......	....	......	......	1.18
Dec. 31, 1900	St. Paul, Minn.	6 in.	......	......	......	1 in.	......	....	......	......	1.67
Sept. 3, 1900	Toledo, Ohio	6 in.	......	......	......	1 in.	5 yrs.	19	1.75	1.62	1.53
Feb. 18, 1901	Toledo, Ohio	6 in.	......	......	......	1 in.	5 yrs.	8	1.80	1.69	1.47

The average of the minimum prices above shown for the pavements on concrete base = $1.51

also the highest bid and the mean of all the bids, for use in preparing estimates of cost for similar works.

GUARANTEE.

Some cities now require that the price for a brick pavement shall include a guarantee that it will be kept in good condition for a term of years and delivered in good condition at the expiration of this time. This term varies widely as indicated by the records of fifty-five cities of the United States which had, on January 1st, 1899, 571 miles of brick pavements: of these, three require guarantee for one year; two for three years; thirty-two for five years; one for six years; one for seven years, and ten for ten years; while eleven require no guarantee, some buying the brick and laying them by hired labor. The general tendency seems to be toward a five-year guarantee with a surety company bond.

UNION SQUARE, NEW YORK, 1900.

Looking up Broadway at Fourteenth Street: after paving with sheet-asphalt in 1900: Trinidad Lake wearing surface, 2 inches; Bermudez Lake binder-coat, 1 inch.

AMERICAN SHEET-ASPHALT, ARTIFICIAL AND NATURAL.

COMPARATIVE QUALITIES OF PAVEMENTS.

Asphalt pavement ranks first in extent of use and in satisfactory qualities, being fairly durable, and cleaner and less noisy than brick. Vitrified brick, the latest and best types of wooden blocks and the more recent bituminous macadam, are its rivals for public favor.

HISTORY OF ASPHALT PAVEMENTS.

The original pavements were made in Paris in 1854 and were formed of pulverized natural asphalt rock, mined at different places in France and Switzerland and Sicily. This rock is a natural combination of eighty-eight per cent of amorphous carbonate of lime, with twelve per cent of mineral tar or bitumen, forming a bituminous limestone, and is generally used for the comparatively small amount of asphalt pavements in European cities.

A similar combination of sandstone and seven per cent to thirteen per cent by weight of bitumen is known as Kentucky sand-rock asphalt, and is used in some of the cities of the United States, having an advantage over the European bituminous limestone in being less slippery.

American Asphalt Mixture.—The artificial mixture of sand and asphalt was first used in Newark, N. J., in 1870, and on Fifth avenue in New York in 1873, though its first extensive use was in Washington in 1877. It has since been laid in vast quantities in about 100 cities of the United States and is the best-known form of asphalt pavement. The proportions and methods have varied somewhat with the gain in accurate knowledge and with the judgment of the builders and with the local conditions.

This artificial mixture, which forms an artificial bituminous sandstone, and also the Kentucky natural sand-rock, give better results than the European rock-asphalt, in that the sand which forms their greater part, affords a better foot-hold, so that fewer horses slip upon them and still fewer fall. Since 1883 Buffalo has paved with sheet-asphalt 217 miles of street having an average width of roadway of thirty feet, at a cost of over eleven million dollars, while Philadelphia has laid 235 miles; these cities alone having more than the combined mileage of all the European cities. The cities of the United States have in 1901, over 2,600 miles of asphalt-paved streets, stated by Major J. W. Howard, engineering editor of Municipal Journal and Engineer, to represent an investment of ninety-five million dollars.

American Natural Sand-rock Asphalt.—To form this pavement, the quarried rock is ground and heated to 300° Fh., and taken to the work hot and spread directly upon the clean concrete base where it is then rolled and rammed into a compressed layer two inches thick, no "flux" and no "binder coat" being needed.

The sand-rock is sometimes used in combination with bituminous limestone in proportion varying from one and one to two and one.

BARTON STREET, BUFFALO, N. Y., October 5, 1901.
AMERICAN NATURAL SAND-ROCK ASPHALT, LAID AUGUST, 1891.
Pavement in perfect condition after ten and one-half years' use, during which time, there have been no repairs of damage due to wear or weather.

There seems no good reason why the American bituminous rocks should not be so systematically laid as to give for the cities of the United States, pavements which are as good as, or are better than, those made for the cities of Europe, with their bituminous limestones. Buffalo has had about ten miles of American sand-rock pavement since 1890–1892; Frank V. E.

Bardol, M. Am. Soc. C. E., who has had charge as chief engineer of the department of public works of all the pavements of Buffalo for many years, states that these "rock-asphalt pavements have required practically no repairs, although they have been laid from seven to eleven years." This pavement was laid with five-year guarantee on ten miles of fifty-one streets. The needed repairs made since the guarantees expired, have been confined to three miles of thirteen streets, nine to eleven years old, at a total cost of an average of three and eight-tenths cents per square yard of the total area of these streets. The accompanying view was taken in 1901, of a street which has had no repairs since it was thus paved in 1891, and now shows good results.

The average annual cost of repairs of this sand-rock asphalt pavement is put by Mr. Bardol at one cent per square yard, or one-third to one-fifth of the annual cost of repairs to artificial sheet-asphalt. Front street in San Francisco was paved with rock-asphalt in 1890 and has had an exceptionally heavy traffic, but it is in perfect condition in 1902, having had no repairs during eleven years of use.

In any northern city having either kind of sheet-asphalt pavement, there will usually be during each year two or three days or parts of days when the asphalt will take a coating of ice upon which travel will be difficult unless sharp sand is strewn upon the roadway, but this is a small item in comparison with its many advantages.

Appreciation of these advantages is shown in the Borough of Brooklyn (of whose department of highways, George W. Tillson, M. Am. Soc. C. E., who is a recognised authority on "Pavements and Paving Materials," is chief engineer), where, during 1900, artificial sheet-asphalt was substituted for, or laid upon, other pavements on forty-three streets, equal in area to sixteen miles thirty feet wide.

During the same year in the Borough of Manhattan, sheet-asphalt was also laid upon or in place of other pavements on sixty-four streets, equal in area to twelve miles thirty feet wide, and in the Borough of the Bronx, the same was done on fourteen streets, equal to four and one-half miles thirty feet wide. Of one group of twenty-four proposed paving works, seventeen were for replacing or covering old pavements with sheet-asphalt. See "Foundation" on page 113.

VARIOUS COMPANIES.

Since 1877 many different methods of construction have been tried and a number of companies have been, and some are still, before the public as competitive builders of asphalt pavements. To do this successfully and with certainty requires skill and knowledge which can only be acquired by long and costly experience. A great city may well employ experts who can specify details and test materials and direct operations as has been and is done in Washington and New York, but cities of moderate size desiring to build a few blocks, or a few miles, of asphalt pavement, should not attempt to direct the details of construction and should not consider other offers than those made by some of the few great firms having the widest experience and possessing the necessary exact knowledge of all of the many essential details and having the best established reputations, who can safely assume all responsibility for materials and methods and can give an effective guarantee at reasonable cost, for a period of ten years; five years not covering the critical time.

COURT SQUARE, SPRINGFIELD, MASS. 1900
Rock-asphalt laid in front of City Hall in 1897 and repaired in 1898.

Sources of Supply.—There are many sources of supply of different asphalts, each varying from the rest and each requiring its own treatment. Formerly that from Lake Trinidad was assumed to excel all others for forming the American asphalt mixture; but large deposits were discovered in 1899 in northern Venezuela in addition to Bermudez Lake in the Department of Sucre, which alone is eight times the size of Lake Trinidad. There is also in Venezuela another newly found deposit of asphalt near the Gulf of Pavia in the Orinoco delta, and another in the state of Jujuy in Argentina.

The American supplies of Kentucky sand-rock and of California sand-asphalt are very large and are free from international complications.

MATERIALS AND METHODS; AMERICAN ARTIFICIAL SHEET-ASPHALT PAVEMENT.

Asphalt.—The full details of the materials and of the methods of construction are omitted here, but those which are given are based upon the practice during 1900 in the city of Washington, where closest attention is given to the subject by the engineer commissioner of the District of Columbia, aided by Prof. A. W. Dow, whose expert ability is widely known. Trinidad and Bermudez asphalts are used with results which appear to be equally good. They are "refined" by simply evaporating the water which occurs with them in their crude state, and which forms about one-third of the Trinidad Lake asphalt. This refined asphalt must be softened to be useful as a paving cement, and for this effect there is used a flux, which is generally a heavy mineral oil or petroleum residuum.

Asphalt cement is the result of mixing eighty-one to eighty-seven parts, by weight, of refined asphaltum, with nineteen to thirteen parts of flux. This forms the matrix of the asphalt pavement, constituting nine and one-half to twelve and eight-tenths per cent, or an average of nine and seven-tenths per cent by weight of the asphalt mixture forming the wearing surface.

Asphalt cement of a softer consistency is formed by mixing seventy-two to seventy-eight parts of refined asphaltum with twenty-two to twenty-eight parts of flux. This forms the matrix of the "binder," or about five per cent of its total weight, or about eight per cent of its bulk.

Skill and care are required to vary the amount of flux, so as to produce the uniform results necessary for a reliable pavement.

Asphalt Mixture.—The "asphalt mixture" above referred to is formed by mixing about nine and seven-tenths parts by weight of asphalt cement with ninety-one and three-tenths parts of hot sand and stone-dust and limestone dust: the asphalt cement varying during 1900 from a minimum of nine and five-tenths to a maximum of twelve and eight-tenths per cent. This limited amount of asphalt cement is less than the actual voids in the sand, but the "mixture" becomes too plastic, and forms waves when rolled, if the attempt is made to use enough asphalt cement to wholly fill the voids which are probably equal to at least five per cent after it is rolled and finished.

Sand.—The careful and exact testing and proportioning of the sands and the stone-dust and limestone dust are a special feature of later practice. Formerly it was only required that sand should be clean and free from objectionable matter, but since 1894 it has been recognized that there are many varieties of sand, no two deposits being alike and no deposit being uniform. Samples are now taken constantly and are heated to a proper degree of dryness, and then passed over a series of screens to determine the relative proportions of each size.

The composition of each of the various sands which are available being thus learned by tests, two or more kinds are combined in certain proportions, using great care from day to day to obtain a perfectly uniform mixture having a minimum of voids. These voids are in turn filled, as nearly as possible, by adding a varying proportion—averaging about one-tenth of the weight of the sand—of finely powdered silica or fine stone-dust.

Limestone dust was formerly used exclusively for this purpose, but during recent years powdered silica or powdered mineral of any kind has been used instead and has been thought to be better in some ways: but the latest evidence in 1900 is said by Prof. A. W. Dow, to show that powdered limestone acts differently in some way and that the toughest and best asphalt is produced when, in addition to the stone-dust, powdered limestone is also used.

The sand resulting from these admixtures had the following proportions as the average mesh composition of the sands used during 1900. The voids were the least possible and were probably not more than twenty-five per cent nor less than twenty per cent when the sand was shaken and packed as closely as possible.

Percentages of the sand retained on sieves as follows:

10 meshes per linear inch	none.
20 meshes per linear inch	6.3 per cent.
40 meshes per linear inch	30.1 per cent.
60 meshes per linear inch	23.7 per cent.
80 meshes per linear inch	15.6 per cent.
100 meshes per linear inch	7.8 per cent.
passing 100 meshes per linear inch	16.5 per cent.
	100.0 per cent.

This accurate proportioning of the sand and of the stone-dust to fill its voids was found necessary in order to prevent the uncertainties caused by the variation in character of the sand in different localities—it proving cheaper to go to this expense and trouble than to make good the failures which formerly occurred when all care had apparently been used in making and placing the ordinary mixture. This has been done since 1894 by the best equipped companies, who have learned the necessity, and the details, from experience and who are therefore able to guarantee their work in a way which was not formerly possible.

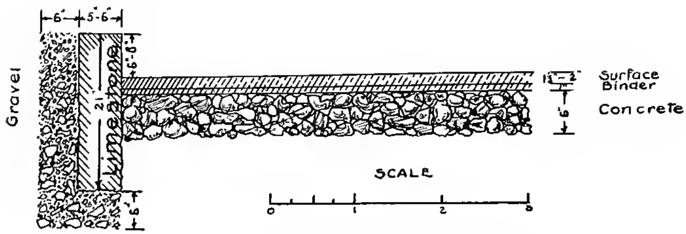
Crushed Stone for "Binder."—Crushed stone to form the "binder" consists of any tough, hard rock and is the total product of the crusher passing through a one and one-quarter inch screen, with some of the dust removed and with the coarse screenings of the sand added.

Ninety-five parts of this by weight are mixed while hot with about five parts of the softer asphalt cement before described.

The amount of asphalt cement varies with the character of the stone, the hot asphalt cement being added in the mixer until all faces of each fragment are coated, but avoiding any excess of asphalt which might tend to fill the voids between the fragments of stone.

FORMATION OF THE PAVEMENT.

Foundation.—If the street has never been paved, the base of the proposed asphalt pavement is made of hydraulic cement concrete four inches or six inches thick. The usual practice is here shown and in the table on page 56.



Asphalt Pavement

Much of the sheet-asphalt laid in the great cities has been put directly upon old pavements of cobbles or of stone blocks, of which the depressions may be filled with hot crushed stone sprinkled with hot asphaltic cement, or which may be merely re-set at points of subsidence to restore the regular form, but which are usually re-set at three inches lower grade and with the proper crown in order to make room for the "binder" and the "wearing surface" of asphalt, without having to raise the manholes, car-tracks and curbs. The lower part of Seventh Avenue, New York, was thus treated during 1901. The joints between the stones of the old pavement should be three-fourths of an inch wide and should be brushed and cleared for at least an inch in depth to afford a firm hold for the "binder."

In some instances, stone blocks for a base have been re-laid flat to give a lower grade, but this is not good practice and has given poor results unless there is a concrete base beneath the old blocks, as was the case in New York on Broadway below Forty-second street to Canal street which was thus treated in 1901.

Brick pavements built in 1887 have been used as base for sheet-asphalt for many miles of streets in Columbus, Ohio.

Old macadam roads have often been successfully used as foundation for sheet-asphalt, and this may work well until cuts are made for sewer and water and gas connections when it will be difficult to restore the pavement.

Binder. — The mixture of stone and asphalt which has been described at page 112, is brought hot from the mixer and is spread over the clean and dry base, using rakes to give it a regular depth of two inches, where it is at once compressed to one and one-half inches with a steam roller which may be slightly sprayed with water to prevent adhesion.

When completed, this "binder" must be firm so that fragments are not displaced by the passage of construction teams, but the surface must be open and "honey-combed" so that it may give a good hold for the "wearing surface" which should follow at once if possible and certainly on the same day. All traffic must be kept off during whole progress of work.

If the fragments of binder are not firm, or if its voids are filled by excess of asphalt cement, such portions must be removed and replaced by perfect material.

Asphalt work of all kinds should stop during rain, or snow-fall, or freezing weather.

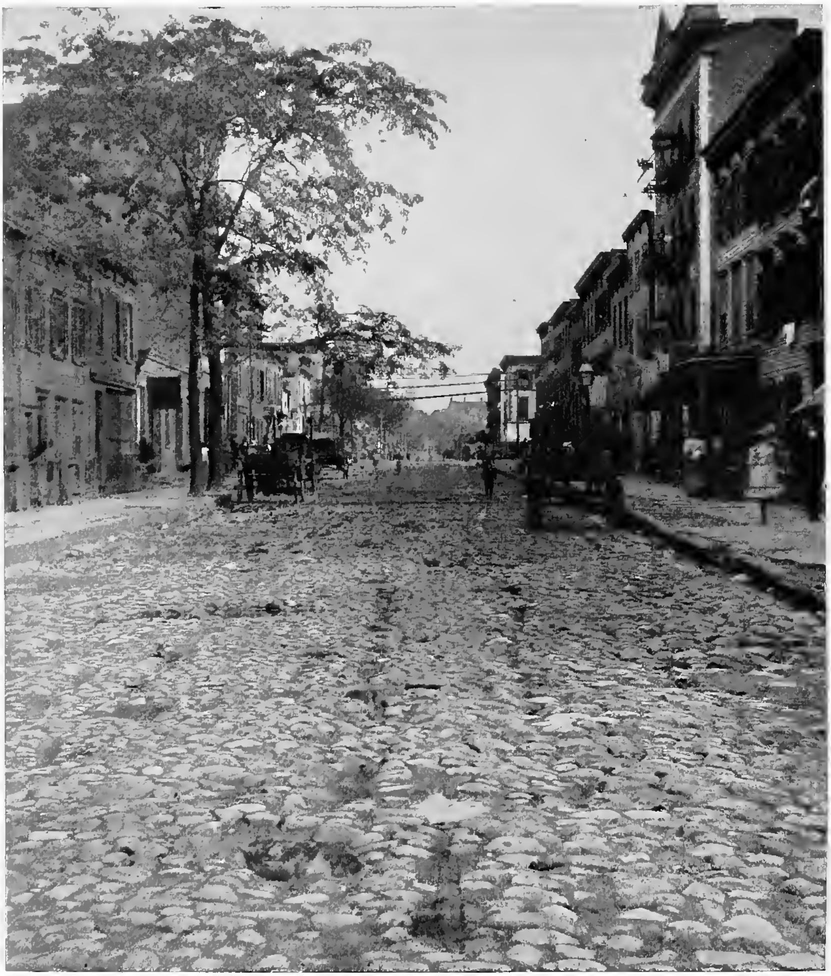
Wearing Surface.—This is formed of the "asphalt mixture" which has been described on page 110, and must be brought hot from the mixer and should reach the work with a temperature of about 280° Fh.: the surface of the "binder" should be swept perfectly clean to receive it, and it should be spread with hot rakes to a uniform depth of two and one half inches of the loose material, taking care to loosen that coming from near the bottom of the cart which must be scraped clean after every load. The loose layer is spread two and one half inches deep to form a one and one half inch finished surface, or three and one-third inches to form a two-inch surface, which latter is much the better for heavy traffic.

Rolling the Wearing Surface.—The "asphalt mixture" is then rolled with a cold 1200-pound hand roller, the surface of which is constantly wiped with a piece of oily cotton-waste to prevent adhesion.

After this rolling which is done quickly, the surface of the asphalt is covered with finely ground dry mineral dust (generally using dry hydraulic cement), which is swept over the surface to give it the soft gray color which is desired and to prevent the adhesion of the five-ton finishing roller with which the "wearing surface" is rolled until compressed to one and one half inches or two inches in thickness and until the surface is perfect. Cities are about equally divided as to which of these thicknesses is used, as indicated in table on page 56.

This rolling will usually occupy about one hour on sixty feet length of pavement thirty feet wide.

The entire manipulation of the material, and especially its spreading and rolling, require skill and care not only for the general features here described but also for many other important details which are necessary to secure good results.



CARROLL STREET, BROOKLYN, NEW YORK, 1900.
Before covering cobble pavement with sheet-asphalt in 1900.

CARROLL STREET, BROOKLYN, NEW YORK, 1900.
After paving with Trinidad sheet-asphalt in 1900.

GRADE AND CROWN.

The actual steepest grades existing in various cities are shown in the accompanying table, in order that those having doubts in any extreme case may examine some of these grades and observe the results.

Actual Grades of Sheet-Asphalt.

CITY.	State.	Ft. per 100 feet.	CITY.	State.	Ft. per 100 feet.
Buffalo	N. Y.	5.1	Pittsburg	Penn	17
Erie	Penn.	5	Salt Lake City.	Utah.	5
Grand Rapids	Mich.	7	San Francisco	Cal.	16
Hartford	Conn.	5	St. Joseph	Mo.	8
Marion	Ohio	5.75	Scranton	Penn.	13
New York	N. Y.	5	Syracuse	N. Y.	7
Omaha	Neb.	8	Toledo	Ohio.	5
Peoria.	Ill	7.2	Troy	N. Y.	7.5

The crown used in various cities on level streets is shown in the same way; it being borne in mind that the least crown which will shed water makes the best road for those who use it. See "Crown of Pavement," at page 30.

Actual "Crown" of Sheet-Asphalt.

CITY.	State.	Inches per 30 ft width bet curbs	CITY.	State.	Inches per 30 ft width bet. curbs.	CITY.	State.	Inches per 30 ft width bet. curbs.
Albany	N. Y.	5	Fort Wayne	Mich	4	Muncie	Ind.	12
Atlanta	Ga.	5	Grand Rapids	Mich	6	New Orleans	La.	5
Binghamton	N. Y.	5	Harrisburg	Penn	5	Peoria	Ill.	6
Buffalo	N. Y.	5	Hartford	Conn	4½	Sandusky	Ohio	6
Charleston	S. C.	4	Houston	Texas.	6	Scranton	Penn	5
Columbus	Ohio	6	Jackson	Mich	4½	Springfield	Mass	3½
Dayton	Ohio	4½	Joliet	Ill.	5	St. Paul	Minn	5½
Detroit	Mich	3⅔	Mansfield	Ohio.	5¼	Terre Haute	Ind.	7
Elmira	N Y.	4½	Meridan	Conn	4¼	Toronto	Ont	7
Erie	Penn	6	Milwaukie	Wis	11	Troy	N. Y.	5½

RAILWAY TRACKS IN ASPHALT-PAVED STREETS.

When railway tracks are laid in streets paved with asphalt, there is wide variation in the manner of construction next the rails: of fifty-two cities having this condition to meet, all have, until recently, put some other material than asphalt next to the rails: fourteen using granite blocks, six using stone blocks, and fourteen using vitrified brick.

The best practice in Buffalo, Rochester, Pittsburg and elsewhere, is to use ninety-pound rails with nine-inch or ten-inch webs welded in continuous lengths, and placed on twelve-inch concrete base to insure rigidity: the asphalt surface being then laid in contact with the rails. See page 40.

The practice in Rochester since 1899 and in Pittsburg in 1901 has been to first place the heavy steel rails accurately on line and grade with temporary supports, and then to form the twelve-inch concrete base beneath the rails; ramming and tamping the concrete until it rises against the rail-base and gives it a perfect bearing at all points without having to use wedges.

COST OF SHEET-ASPHALT.

This varies widely with local conditions and with the competition and can best be seen by reference to the tables here and at page 56, showing rates with and without concrete base and curbs.

PRICES FOR SHEET-ASPHALT PAVEMENT,

NOT INCLUDING BASE OR CURBS OR EXTRA WORK.

DATE.	PLACE.	Guarantee.	No. of Bids.	PRICE PER SQ. YD.		
				Max.	Aver.	Min.
Oct. 1, 1900.	Albany, N. Y.	10 yrs.	4	$2.17	$1.91	$1.34
Jan. 1, 1901.	Cedar Rapids, Iowa.	....	3	2.02	1.83	1.69
Sept. 26, 1900.	Cincinnati, Ohio	5 yrs.	5	2.31	2.21	1.97
Oct. 1, 1900.	Owensboro, Ky	....	3	2.09	1.93	1.80
Sept. —, 1900.	San Antonio, Texas	10 yrs.	4	2.00	1.56	1.40

INCLUDING 6 INCHES OF CONCRETE AS BASE.

DATE.	PLACE.	Guarantee.	No. of Bids.	PRICE PER SQ. YD.		
				Max.	Aver.	Min.
Aug. 7, 1900.	Aurora, Ill.	5 yrs.	5	$1.97	$1.88	$1.81
March 3, 1901.	Baltimore, Md.	10 yrs.	......	2.27	......	2.17
Aug. 1, 1900.	Cortland, N. Y.	10 yrs.	2	2.35	2.34	2.33
—— —, 1899.	Fort Wayne, Ind.	10 yrs.	......	......	......	1.89
March 4, 1901.	Houston, Texas	10 yrs.	3	2.90	2.42	2.00
—— —, 1899.	Joliet, Ill	5 yrs.	......	......	......	1.51
—— —, 1899.	Milwaukie, Wis	5 yrs.	......	2.23	......	1.95
—— —, 1899.	New Orleans, La.	5 yrs.	......	......	......	2.13
—— —, 1898.	Oswego, N. Y.	5 yrs.	......	......	......	1.95
—— —, 1899.	Peoria, Ill.	5 yrs.	......	......	......	1.70
—— —, 1899.	Rochester, N. Y.	10 yrs.	includ-ing excav.	2.26	2.04	1.70
—— —, 1899.	Sandusky, Ohio	5 yrs.	......	......	......	1.53
Dec. 31, 1900.	St. Paul, Minn.	10 yrs.	......	......	......	2.62
Sept. 3, 1900.	Toledo, Ohio.	5 yrs.	......	2.65	2.27	2.10

NOTE.—Mainly from the columns of the Engineering News and of the Engineering Record.

GUARANTEE.

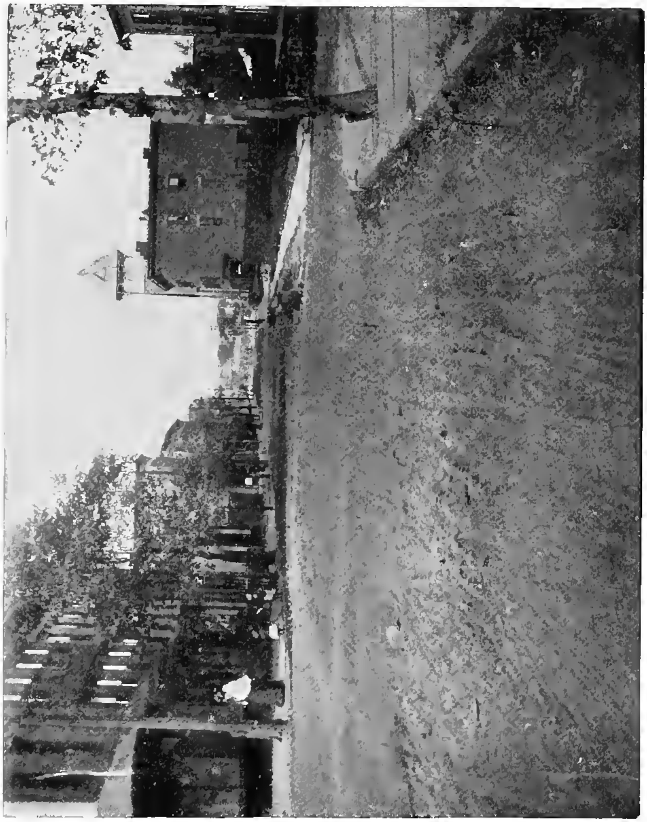
It is now usual to require that the price paid for a sheet-asphalt pavement shall include a guarantee that it will be kept in good condition for a term of years and delivered in good condition at the expiration of this time: this term varies as is indicated by the records of forty cities of the United States which had, on January 1st, 1900, 757 miles of sheet-asphalt pavement: of these, twenty require guarantee for five years and twenty require a guarantee for ten years. Ten of the latter have formerly required five years, but now require ten, showing a tendency toward a ten year guarantee. Maintenance guarantees for long terms were required for the sheet-asphalt pavements of Fifth avenue and of Broadway, New York. Asphalt was laid in 1896–7 on Fifth avenue with fifteen years' guarantee at the following prices per square yard, including new concrete base: from Ninth street to Fifty-ninth street, the cost was $4.35: from Fifty-ninth street to Eightieth street, $4.00: from Eightieth street to Ninetieth street, $3.29: these different rates indicating the expected effects of traffic on the cost of maintenance.

Asphalt was laid in 1900 on Broadway, with fifteen years' guarantee, from Fifty-eighth street to Fourteenth street, upon new concrete base to Forty-second street and upon the old stone blocks relaid flat upon two inches of sand over the old six-inch to eight-inch concrete base below Forty-second street. The cost was $5.37 per square yard.

Asphalt was extended in 1901 down Broadway to Canal street, and cost $6.31 per square yard. This included fifty-nine cents for relaying the old blocks flat upon the old concrete base and also ten years' maintenance. This should include strewing sharp sand when the pavement is slippery, as on Fifth avenue and on all wood-block and asphalt pavements abroad.

The average cost of a guarantee in Buffalo is put by F. V. E. Bardol, M. Am. Soc. C. E. (see page 56), at three cents per square yard for the first five years and fifteen cents for the second five years or eighteen cents for ten years.

The probable cost of a guarantee for the third five years would in some cases equal the cost of an entire renewal of the surface.



EAST AVENUE, LONG ISLAND CITY, N. Y., 1900.

Before paving with asphalt, October 1st, 1900.

EAST AVENUE, LONG ISLAND CITY, N. Y., 1900.
After paving with Bermudez Lake sheet-asphalt, October 30, 1900.

CAUSES OF FAILURE OF SHEET-ASPHALT.

A reasonable amount of traffic tends to prolong the life of a good sheet-asphalt pavement. When a pavement begins to fail, the causes are probably to be found in about the following order:

First.—Defective foundation, which has settled and caused the hollows in which pools of water have stood upon the surface of the asphalt until it has become disintegrated.

Second.—Wearing surface too soft, or excess of asphalt in binder, or dirt on surface of binder, either of which may allow "wearing surface" to creep under traffic and to form waves or rolls, in which the sheet of asphalt mixture is thickened, alternating with hollows where it has become thin.

Third.—Patches where the pavement has been torn up for sewer and water connections and not well restored.

Fourth.—Surface cracks, which sometimes appear in cold weather as a result of excessive contraction of the surface, and which sometimes close and re-unite in warm weather under the combined effects of warmth and of passing wheels.

Fifth.—Excessive traffic which has worn off the surface. This is the least common.

Sixth.—Lack of traffic, allowing the asphalt to become spongy. The latter cause usually shows its effects at the sides of the roadway next the curbs, where there is least passage of wheels. The process of failure may then be as follows:

The material composing the sheet of asphalt expands slightly with the sun's heat, as all other substances do; but unlike most other substances, it does not of itself at once return to its original thickness when the heat is lost, because the asphalt becomes rigid as it cools, and unless compressed by force, tends to remain in its expanded form. In the center of the roadway, where most of the wheels pass, the asphalt is at once re-compressed, but at the sides this is not done so promptly, with the result that there is a tendency to become somewhat porous or spongy where there is little traffic. When at last the asphalt has thus actually become porous, water can permeate it, and this soakage of water is helped by the fact that the surface-drainage is toward the sides, where the material is most likely to absorb some of it. Having thus absorbed ever so little moisture, of course both heat and frost have increased

JEFFERSON AVENUE, BROOKLYN, 1900.
Destructive effects of gas leaks on sheet-asphalt pavement.

effects upon the material, and ultimately it shows signs of disintegration.

Seventh.—When a failure of asphalt is so complete as to include several of these features, it will usually be found that the pavement was built by some local paving company, without previous experience, whose bid should not have been considered and whose work and guarantee proved to be equally worthless.

Eighth.—Disintegration of surface may also result from defects in the mixture of asphaltum and flux or from the laying of the pavement during freezing weather; disintegration is frequently caused, especially in Brooklyn, New York and Kansas City, by the escape of illuminating gas from leaky mains. The hydrocarbons which are now used in these cities to enrich and cheapen illuminating gas, are solvents of asphaltum; leaks of this destructive and tenuous gas from the underlying main pipes are the direct cause of failures like those shown in the accompanying photograph of Jefferson avenue, Brooklyn, taken in 1900.

Disintegration of asphalt is also caused by the spilling of kerosene by careless vendors, and by the dropping of oil from the axle-boxes of street-cars.

Bonfires are sometimes built on asphalt pavements with destructive effect, and this was done in one case with a misdirected desire to celebrate the completion of the pavement which it injured. Most of these causes of failure are preventable by proper selection of the builders or by proper care of the finished work.

There are many cases—among them Oswego, N.Y., as shown on the frontispiece—where no defects of any kind have appeared during and after five years' use of the pavement.

BLOCK ASPHALT PAVEMENT.

Asphalt blocks are used in many cities of the United States, there being in 1900 the equivalent of ninety-five miles of pavements, thirty feet wide. During 1900, twenty-one streets, equal in area to three miles, thirty feet wide, were thus paved in the Borough of Manhattan, equaling twenty-five per cent of the sheet asphalt laid in 1900.

Washington, in July, 1900, had twenty-two miles of such pavement, as compared with 141 miles of sheet-asphalt. The asphalt blocks laid in 1900 were formed of thirteen per cent asphaltic cement, ten per cent limestone dust and seventy-seven per cent crushed gneiss, and cost $1.77 per square yard laid, not including base.

The character of asphalt blocks has been much improved during recent years and the proportions are now usually about as above stated, except that crushed diabase trap or basalt is generally used and with better results. The materials are heated to 300° Fh. and are mixed in a rotary mixer until all the faces of every particle of the crushed stone are perfectly coated with the mixture of asphaltic cement and limestone dust. The product is then put in moulds twelve inches long, four inches or five inches wide and three inches or four inches deep and subjected to a pressure of two to two and one-half tons per square inch and then slowly cooled in water. This is done in a factory where the best results may be obtained and the blocks are then shipped to their destination, where they can be laid, like brick, in cold weather, if necessary, by unskilled labor.

This last feature constitutes their chief advantage over sheet asphalt. The blocks are laid in close contact, sometimes on gravel covered with sand, though a concrete base is best, upon which the blocks are sometimes bedded in one inch of Portland cement mortar.

Asphalt blocks made as above described, have worn well, but there are few cases where sheet-asphalt is not preferable. The following table shows the prices of recent pavements of this kind:

PRICES FOR BLOCK-ASPHALT PAVEMENT, FOUR INCHES THICK, INCLUDING SIX INCHES OF CONCRETE AS BASE AND FILLER IN JOINTS.

Date.	CITY.	State.	Guarantee.	No. of bids.	Price per Sq. Yard.		
					Max.	Aver.	Min.
Mar. 11, 1901	Annapolis	Md	5 yrs.	2	$2 85	$2 80	$2 75
Mar. 13, 1901	Chillicothe	Ohio	....	15	1 31	1 17	1 07
Mar. 11, 1901	Pontiac	Mich.	5 yrs.	On 6 in. gravel.	-----	-----	2 40
Sept. 3, 1900	Toledo	Ohio	5 yrs.	18	3 25	2 32	1 95
Feb. 18, 1901	Toledo	Ohio	5 yrs.	3	2 55	2 45	2 25*

* (On sand base, seventeen cents less; on stone base, three cents less.)

A cheaper modification of block-asphalt, known as the Leuba pavement, has been in successful use in Neuchatel, Switzerland, since 1898, and consists of blocks eight and three-fourth inches long, four and one-half inches wide, and four inches to four and one-half inches thick, but with the lower three-quarters of each block made of hydraulic Portland cement and clean, sharp sand in proportions of about one to four: this concrete base being covered with a wearing surface one and one-fourth to one and one-half inches thick of compressed natural rock-asphalt: the two materials being joined under heavy pressure, and the blocks being laid with cement joints on a concrete base.

BLOCK ASPHALT PAVEMENT, NINETY-SIXTH ST., NEW YORK, 1900.
Looking west from Third avenue to Park avenue. Paved in 1900.

List of Cities Having Both Sheet-Asphalt and Brick Pavements.

Miles of each with preference.

City.	State.	Sheet-Asphalt, Jan. 1, 1900.	Brick, Jan. 1, 1899.	Preference.		
				As-phalt.	Brick.	Not stated.
Albany	N. Y.	9 miles	16 miles		—	
Atlanta	Ga	2 miles	2 miles	—		
Baltimore	Md	7 miles	1 mile			—
Binghamton	N. Y.	5 miles	2 miles			—
Boston	Mass	14 miles	1 mile	—		
Buffalo	N. Y.	217 miles	7 miles	—		
Cleveland	Ohio	9 miles	66 miles			—
Columbus	Ohio	15 miles	74 miles		—	
Dayton	Ohio	17 miles	12 miles	—		
Detroit	Mich	22 miles	24 miles			—
Elmira	N. Y	0.8 mile	0.5 mile		—	
Erie	Penn	11 miles	6 miles		—	
Fort Wayne	Mich	7 miles	10 miles			—
Grand Rapids	Mich	6 miles	4 miles			—
Harrisburg	Penn	3.4 miles	0.5 mile			—
Houston	Texas	4 miles	7 miles	—		
Jackson	Mich	0.4 mile	2.5 miles		—	
Joliett	Ill	3 miles	3 miles	—		
Mansfield	Ohio	1 mile	15 miles		—	
Marion	Ohio	1.5 miles	6 miles		—	
Milwaukee	Wis	10 miles	2 miles		On over 4 per cent grades.	
Minneapolis	Minn	13 miles	5 miles			—
New Haven	Conn	3.5 miles	1.5 miles		—	
New Orleans	La	23 miles	59 miles	—		
Peoria	Ill	8 miles	22 miles			—
Philadelphia	Penn	235 miles	120 miles			—
Rochester	N. Y	43 miles	7 miles	—		
Sandusky	Ohio	1 mile	6.5 miles	—		
Scranton	Penn	12 miles	2 miles			—
Springfield	Mass	0.3 mile	1.5 miles		—	
St. Joseph	Mo	9 miles	7 miles			—
St. Paul	Minn	13 miles	3 miles			—
Terre Haute	Ind	3.5 miles	4.5 miles		—	
Toronto	Ont	24 miles	8 miles	—		
Toledo	Ohio	21.6 miles	42 miles		—	
Troy	N. Y	4 miles	8.5 miles		—	
Washington	D. C.	141 miles	1 mile	—		
Total	....	920 miles	560 miles	11	13	13

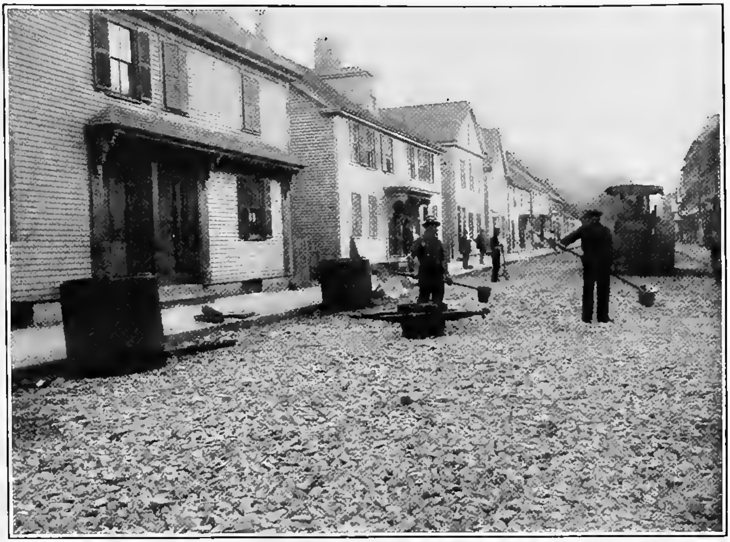
(Compiled by Willis Fletcher Brown, consulting engineer of Toledo, Ohio.)

BITUMINOUS MACADAM, OR BITULITHIC PAVEMENT.

During 1901, a practically new form of pavement with the above name has attracted much attention and has come into use at widely separate places: its favorable discussion in the Engineering News of January 30, 1902, and in the Engineering Record of the same date, has confirmed many in the opinion that this was a new factor in the solution of the paving problem although the test of time is yet to be applied.

The former bituminous or "tar" pavements have usually been formed of sand the fine grains of which have no other stability or structural strength than is derived from the matrix of asphalt or of coal-tar in which they are embedded: or they have consisted of tarred fragments of stone with twenty per cent or more of void spaces, generally placed without systematic heating and mixing.

The new pavement is formed of trap rock, or other tough rock, crushed and screened to fragments varying in size from two inches down to the dust, and combined in such proportion of sizes that the final spaces between the fragments of rock do not exceed ten per cent. This means that the fragments must be in actual and firm contact with each other and that the addition of ten or twelve per cent, by bulk, of bituminous com-



ADAMS STREET, LOWELL, MASS.
Rolling and coating the base.

TEMPLE STREET, CAMBRIDGE, MASS.
Spreading and rolling the wearing surface.

BITUMINOUS MACADAM, 1901.

pound will fill the remaining voids and make a solid and impervious mass.

When this is accomplished, the result must be a pavement which water cannot penetrate and which should support the passage of traffic without abrasion of the fragments upon each other and without the bituminous filler being exposed to action of the weather.

It is obvious that the success of the pavement will be dependent upon the care which is used in the selection of the materials and the skill and thoroughness shown in combining and placing them, and that these features are as important as for an asphalt pavement.

BASE.

The base for the new pavement is prepared as for a macadam road; the earth road-bed being graded, drained, formed and rolled, and then covered with a layer of the best stone available which is crushed and screened to two inches and larger and is rolled with a fifteen ton steam roller into a compact layer four inches thick. This stone base is then sprinkled with a thin hot bituminous mixture and then covered with a coating of thicker hot bituminous mixture which binds the surface of the base and prepares it to receive the next layer which is spread on top of it.

TOP.

The "wearing surface" is then spread while hot, and is rolled and compressed to a final thickness of two inches: this "wearing surface" is formed of the best available rock, preferably trap rock, which has been crushed and screened to retain all less than two inches:

this is then dried and heated in rotary drums and then screened in rotary screens which separate it into the various sizes from two inches down to dust. These sizes are then proportioned, and some sand added if necessary, in such ratio as shall give a minimum of voids not exceeding ten per cent: this low ratio of voids being only possible by careful study.

The heated stone is then run into a mechanical mixer at a temperature not exceeding 300° Fh., together with hot bituminous cement (which may consist of asphalt), in sufficient quantity to fill all voids and to coat all faces of all particles of stone and dust and sand, and also to provide a slight surplus of "filler." When thoroughly mixed by about 150 revolutions of the mixer, it is hauled to place on the street and is spread and rolled in the same manner as asphalt, but using a fifteen to twenty-ton steam roller to compress it and to crowd the bitumen into all the voids, forcing out all air-bubbles and making the surface as dense as possible.

Upon this surface, filling its irregularities and making it sticky, there is then poured and rubbed a coating of quick-drying bituminous cement, heated to 250° Fh. and over this is spread about a quarter-inch layer of small stone chips which are rolled and forced into the sticky coating forming a final wearing surface: these chips being larger in proportion as the grade is steeper, so that a good footing is given for horses on steep grades.

COST.

During 1901 streets have been thus paved by various city departments, under expert advice and supervision, at New Bedford, Holyoke, Cambridge, Lowell and Brockton, Massachusetts, and at Salem, N. J., and Pawtucket, R. I., and Charleston, S. C.; and the cost has ranged from $1.25 at Holyoke, Brockton and Lowell to $1.50 per square yard at Salem, or about double the cost of ordinary macadam of the same thickness.

The city engineers and officials of these cities have spoken so favorably of it that a number of cities are to follow their example during 1902 at varying costs from $1.80 to $2.75 per square yard, which in each case includes guarantee for five years.

Among these are Taunton, Mass., Norwich, N. Y., Charleston, S. C., Yonkers, N. Y., and three miles of "State Road" leading south from Cleveland, Ohio, which last is to cost $1.40 per square yard: also, two and one-fourth miles of Seventh Avenue, New York city, from 110th street to 155th street, which, if done, will cost about $2.75 per square yard: the five year guarantee in this case being important, as the traffic is heavy.

WIDTH AND GRADE.

The pavement usually extends from curb to curb, the widest built being forty feet at Salem, N. J., and the narrowest being sixteen feet proposed near Cleveland, Ohio.

The steepest grades are eight feet to twelve feet per 100 on Harvey street, Pawtucket, R. I., and ten feet to fifteen feet per 100 proposed at Yonkers, N. Y.

OPINIONS.

This new pavement has been in actual use only since January, 1901, but the opinions expressed by

MAPLE STREET, HOLYOKE, MASS., 1901.
Before and after paving with Bituminous Macadam.

skilled road-builders, who have examined it critically, are favorable as to its durability and value.

In addition to the officials of the various cities named, many city engineers and street superintendents have examined these pavements during and after completion, and intend to build similar ones in their various localities, it being found that the winter and spring of 1902 have left these in good condition.

Among these are the president of the Massachusetts highway association, C. A. Brown of Cambridge; the vice-president of the Massachusetts highway association, R. A. Jones, of Waltham; Prof. A. W. Dow of Washington, D. C., who is quoted by the Municipal Journal as expressing the opinion, based upon what he knew of it, that this pavement exceeded in good qualities any other pavement that he had seen laid. Chas. W. Ross of Newton, former State highway commissioner of Massachusetts, commended it to the convention of supervisors of New York State at their annual meeting at Albany on January 28, 1902, saying that its use would prevent the storm-washing of macadam streets on steep grades and would have saved Newton from damages amounting to $20,000 which were caused by a single shower in July, 1901.

With such weighty opinions from unbiased experts, it is evident that this pavement is a factor to be considered in future projects for city streets.

BROKEN-STONE ROADS.

In the recent wide discussion of "Good Roads," macadamizing or some more or less similar arrangement of small fragments of broken or crushed stone, is most often spoken of, and the general reader who has given no special attention to the subject further than to read the many articles which appear in papers and magazines is most likely to conclude that some such construction suits all conditions and localities, though it is really best suited and most used for highways outside of the business parts of cities.

Within the past eight years, there has been an increased use of broken stone roads for residence-streets of cities, resulting from the examples of good work given by the governments of various states in building highways by state aid outside of corporate limits, and thus familiarizing city officials with the methods by which the best roads of this kind can be built and maintained.

This is especially manifest in the cities of Massachusetts, where over 200 miles of macadamized streets have been built since 1894 in the cities of Brookline, Cambridge, the Newtons, Medford and Springfield, as well as 240 miles in Boston. Also in many cities of New York State, especially in a section of Buffalo, near Delaware Park. The city of Greater New York leads in this as in all things, the five Boroughs having on

January 1st, 1901, the following stated miles of macadam streets and boulevards. Manhattan, eighty-two miles; The Bronx, ninety-one miles; Brooklyn, eighty-two miles; Richmond (Staten Island), 183 miles; Queens (on Long Island), 388 miles; Central Park, nine and a half miles (all telford, 1869 to 1878); Prospect Park, six and a half miles; Greenwood, twenty miles; or a total of 862 miles of broken-stone roads within the city, practically all but forty-five miles built since 1894.

The building of rural roads by state aid was begun in 1893 by the State of New Jersey, which pays one-third of the cost of construction; followed in 1894 by the State of Massachusetts, which pays three-fourths of the cost, and by Connecticut in 1895, which pays two-thirds to three-fourths of the cost, and by New York State in 1898, which pays one-half of the cost: the balance in each case being paid by the towns or counties. In Maryland, the state aids the counties by making their surveys and plans and directing the improvements.

Under these systems, the roads most considered and most built have been of the two principal types of construction known as the macadam and the telford, though many miles of gravel roads have also been built and many miles of highways in each state named have been merely improved by forming and draining the natural materials as found, with the idea that this work may be later continued by putting broken stone upon the roadways thus begun.

ROCK FOR ROADS.

Trap.—The three states first named are fortunate in having many formations of good rock for road construction, while New York State is mainly limited for the best grade of rock to the diabase-trap or dolorite formation lying on the Hudson River in Rockland county, just north of Nyack and opposite to Sing Sing or Ossining.

This lies ten miles north of the limit of the proposed Palisades Reservation, is more accessible by canal boat and by railroad than any part of the Palisades and contains enough material of the best grade to macadamize all the roads in the state. The many quarries of New Jersey and Connecticut are also available for roads in New York as well as in those states. There was also discovered in 1901 a large isolated mass or "plug" of trap rock, near Schuylerville, N. Y., about twenty miles north of Albany, lying close beside the Champlain canal and the railroads. Other similar formations have been found in Clinton county by the State Geologist, Professor F. J. H. Merrill. Trap rock is the best for road construction, in that it has no true cleavage and breaks irregularly with toothed surfaces, and is tough and does not easily grind into dust and mud. Its specific gravity is great, so that its dust does not blow so readily as that of limestone.

Porphyry is ranked next, but it is not common and the supply in New York State is limited to Lake Champlain.

Quartzite, and *siliceous quartzite* are more common and in some cases make very good road-material.

Granite of some varieties is a good road-material, in proportion as it contains a small amount of mica and of quartz, and is not weathered.

The same is true of gneiss and of syenite, which are granitic and of which large and accessible formations exist at Little Falls, on both sides of the Mohawk river, where there are unlimited quantities, close to the Erie canal and the railroads. Throughout Westchester county, N. Y., there are many and varying ledges of gneiss, some of which are tough and good, but many of them carry an excess of mica and of quartz and of feldspar, and crumble readily, especially when weathered, and are unsuited to road-making.

Limestone usually binds well and readily and, if unusually hard, makes a good road. Well-known examples of the best limestones, which have been and are much-used for road-making, are the Tompkins' Cove stone and the Clinton Point stone, quarried on the Hudson, forty miles and seventy miles from New York, and the Bethlehem stone, near Albany, N. Y., and the Jammerthal flint-limestone, quarried in the suburbs of Buffalo, N. Y.

Some of the other limestones, which also bind readily and have been used for roads, contain an excess of lime and crush under heavy traffic, and form a light and impalpable dust, which is most objectionable to residents as well as to drivers. This dust is only avoided by keeping these roads constantly wet, entailing an expense for sprinkling which proves to be more costly than to use a better stone which does not form such dust.

Soft limestones form a good lower course to be covered by a harder wearing-surface or top course. The cementing action, so called, of limestone, is purely mechanical, but it serves to firmly bed the fragments and to prevent them from rubbing and wearing against each other. The use of limestone screenings is discussed at page 160, under "Quality of Screenings."

Sandstone or "bluestone" road, built in Ulster county, N. Y., by state engineer E. A. Bond, M. Am. Soc. C. E., in 1900.

Sandstone is only suited for use where better rock cannot be readily obtained, and then only for the base course where it should be covered by a wearing surface of trap or other tough rock. An exception to this must be made in favor of the "blue-stones" of Ulster county, and the five adjacent counties of eastern New York, which are true sandstone and are peculiarly tough. The Ulster county stone binds readily with its own screenings, and has been used to form the whole material of good six-inch macadam roads, which stand well under moderate traffic and are here shown.

Various Kinds of Rock.—Broken stone roads can be well made with various rocks, requiring varied treatment to suit the conditions. The many rocks and the details for their successful use, can nowhere be better studied than in New York State, which probably contains as great a variety of geologic formations as any other equal area in the world.

IMPORTANCE OF UNIFORMITY.

In the selection of material to be crushed for road metal, uniformity in character is of the first importance; material which is uniformly of a second grade being preferable to a mixture of better and worse. Such a mixing of fragments of hard and soft rocks results in quickly crushing the softer pieces and then exposing the harder pieces to excessive shocks from passing wheels.

COBBLE-STONES.

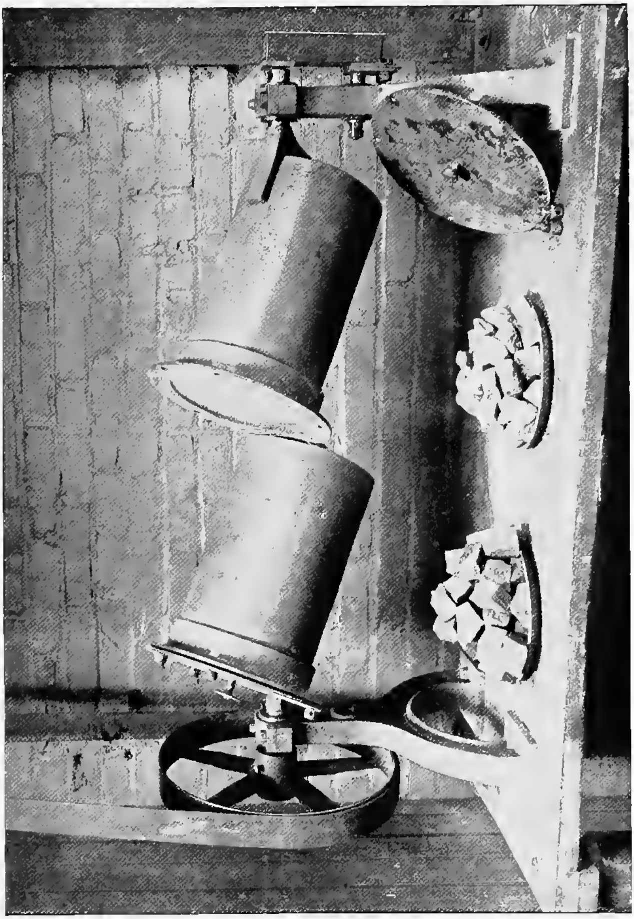
Rounded cobble-stones gathered from the fields and lake shores, make a very poor wearing surface for a road, whatever their composition.

Being worn by action of water or ice into rounded forms, all of the fragments crushed from them have at least one curved or water-worn face. These curved and polished faces prevent the adjacent fragments from coming to a solid bearing in a road. They will always be likely to rock or slide under passing loads, and thus loosen all the fragments which touch them.

Further, these rounded cobble-stones which were strewed broadcast over parts of the country during the glacial period, came from the most widely different localities in the northern part of the continent and include all varieties and degrees of hardness.

Granite, syenite, quartz, limestone, flint and slate were found to make up one-tenth of a mass of them, of which the remaining nine-tenths were sandstone, of which at least one-half were so disintegrated or weather-worn—so "rotten," as the workmen call them—as to be worthless for any purpose: for road-surface metal they are worse than worthless, as their only effect is to destroy the good material with which they chance to be mixed.

Crushed cobble-stones may be selected to form the lower or base course, if nothing better is available, by rejecting all which are inferior and by selecting, to be crushed and screened, only the hardest and best.



Highway Division, Maryland Geological Survey.
ABRASION AND IMPACT TEST OF CRUSHED ROCK.
Standard Deval Machine of 1902.

TESTS OF ROCK FOR ROAD-MAKING.

The various rocks available for road-making are compared as to their relative endurance, by subjecting similar sets of samples of each kind to similar abrasion in machines like that here shown, which was devised by Deval in 1878. Each set of samples consists of eleven pounds, or five kilograms, of roughly cubical selected fragments, none smaller in any way than one and one-quarter inches, nor larger than two and one-half inches. These are cleaned, washed, dried and accurately weighed, and enclosed in one of the cylinders and tightly sealed. Similar sets of samples are put in each cylinder and the whole machine is then slowly revolved at the rate of 2,000 revolutions per hour for five hours, or until a cyclometer registers 10,000 revolutions.

The fine dust worn from each set of samples is then saved for cementation tests, and the fragments are washed, dried and again weighed: comparison of the percentage of loss of each set indicates the relative endurance which is also to be seen by examining the fragments of rocks before and after testing.

The department of civil engineering of Columbia University has a most complete equipment with which Prof. Wm. H. Burr, M. Am. Soc. C. E. has caused to be made many useful tests of road materials, and Harvard is similarly equipped: the testing laboratory of the college of civil engineering of Cornell University, directed by Prof. E. A. Fuertes, M. Am. Soc. C. E., is also fully equipped and makes many tests of stone and bricks for pavements, as does the highway division of the Maryland geological survey at Johns Hopkins University, directed by Harry Fielding Reid by whose courtesy the plates of machines and samples are here given. Records of similar tests of various rocks have been made and published by the highway commission of Massachusetts, by the highway division of the geological survey of Maryland, by the U. S. office of road inquiries at Washington, by the State geologist of New York and by the State engineer of New York and these records are useful guides in selecting stone for road-construction.

MARBLE.

HARD LIMESTONE.

DIABASE TRAP ROCK.

ROCK FRAGMENTS BEFORE AND AFTER ABRASION TEST.
Two-thirds natural size.

HIGHWAY DIVISION, MARYLAND GEOLOGICAL SURVEY.

The following table shows the results of 100 tests of the six kinds of rock most used in Massachusetts and New York:

KIND.	Number of tests.	PER CENT OF LOSS BY ABRASION.		
		Max.	Min.	Mean.
Diabase trap	35	4.31	1.40	2.28
Limestone	24	6.68	2.33	4.34
Granite	10	4.30	2.23	3.52
Quartzite	7	5.90	1.97	3.63
Gneiss	12	6.57	1.73	4.01
Sandstone	12	6.69	1.71	3.56

(The last item includes Medina Sandstone at 2.29 and Ulster "Bluestone" at 3.71.)

Several local rocks are sometimes available of which there may have been no tests, but experience will usually enable a selection to be readily made of the one which will give the best results. The rock which will bind the most readily will probably be the least durable, and it may be more economical to make a long haul of a good rock than to use one which is near at hand, but which will soon need renewal.

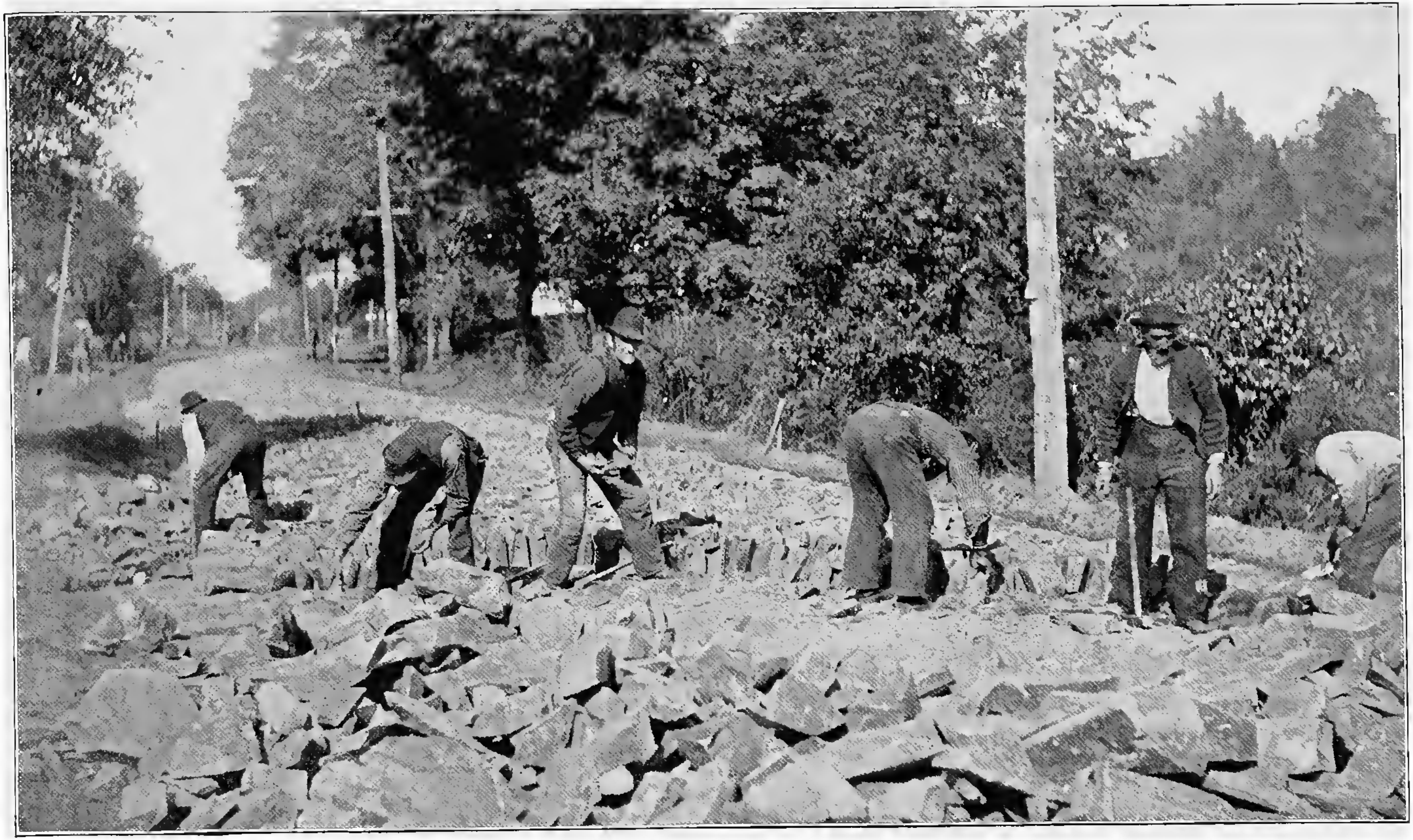
THE MACADAM AND THE TELFORD SYSTEMS.

About a century ago Macadam preached and practiced a gospel of good roads for England with an effectiveness which our leagues of to-day can only hope to imitate in the United States.

England had long had roads of broken stone, and the use of this material was not peculiar to Macadam's method; but he was the first to establish rules of construction which were generally accepted, and under them were built 25,000 miles of road which formed a network all over England; so that his name has come to be associated with broken stone as a road material, although Telford, who came twenty-five years later, used the same material but in a different manner. In Macadam's talk to committees of Parliament and to his workmen, he always enforced the idea that the whole secret of making a good road was to keep its earth-bed dry; that the ground was the real road and must bear the weight of the stones, as well as of the traffic, and that the subsoil, however bad, would carry any weight if made dry by drainage and kept dry by an impervious covering.

In this requirement Telford and all skillful road makers fully agree.

This dry roadbed, Macadam covered with a layer of road metal of a finished thickness of five to ten inches



Laying Telford foundation on a gravel bed.
MASSACHUSETTS HIGHWAY COMMISSION.

(varying with the weight of traffic), composed of small angular fragments of the hardest and toughest rock, broken to a uniform size, as nearly as possible to one and one-half inch cubes, or six ounces each in weight. No dimension larger than two inches was allowed, and any piece too large for a workman to put in his mouth was to be broken again.

In the matter of Telford's foundation for a broken stone road and Macadam's omission of it, there are wide differences of opinion and of practice: French and English engineers generally omitting the telford foundation and many American engineers seeming to tend toward the same practice, or to limiting the use of telford foundations to those portions of roads where the earth subgrade is not firm.

The latter practice is best because where the sub-grade is firm, the telford base serves as an anvil upon which the shocks of traffic break the fragments which form the surface. Where the sub-grade is dry and well drained, the telford base has the effect to more quickly remove the moisture which helps the binder to bed and to hold the surface-fragments. Sprinkling is done in dry weather to supply this moisture and without it the road "ravels." This raveling will occur sooner on a dry section of telford road than on a similar section of a macadam road, but this difference is not so important when the roadway is a city street which is sprinkled and shaded. When the sub-grade tends to being wet, the telford base is desirable as a foundation, and costs, when local stone is at hand, thirty to thirty-five cents per square yard.

COST.

As to the relative cost of the two methods, it is usual that telford is somewhat more expensive, but the following does not so show.

At Somerville, N. J., on October 22d, 1900, proposals were received for two miles of eight-inch macadam and for six miles of ten-inch telford and macadam, each of trap rock, each twelve feet in width, and each including about 2,000 cubic yards of excavation per mile: the prices were in cents per square yard:

	Max.	Min.	Average at 14 bids.
For eight-inch macadam roadway complete..	83	50	62
For ten-inch telford roadway complete.....	83	50	66

For the stone roadways only, not including grading and drainage, for eight roads built in New Jersey, during 1900, the average costs were:

For four six-inch macadam roads, fifty-three cents per square yard; for four eight-inch telford roads, fifty-one cents per square yard.

During 1901, as stated in the report of Henry I. Budd, commissioner, nine eight-inch macadam roads averaged seventy-seven cents per square yard and three eight-inch telford roads averaged sixty-one cents per square yard.

TELFORD ROADWAYS.

The general requirements for construction of telford roadways are similar in the different states with the exceptions which will be named: the earth roadbed or subgrade, is excavated and carefully rolled and formed as for a macadam road, conforming to the proposed cross-sections and twelve inches below the established grade of the finished road.

On this subgrade are then placed by hand the stones forming the telford foundation, which may vary in size as shown below: each stone must be set vertically upon its broadest edge, lengthwise across the road and forming courses and breaking joints with the next course, so as to form a close and firm pavement. The stones are then bound by inserting and driving stones of proper size and shape to wedge the stones in their proper position. All projecting points are then broken with a sledge or hammer so that no projections shall be within four inches of the finished grade-line. The telford foundation is then rolled with a steam roller of ten or more tons weight, until all stones are firmly bedded and none move under the roller. All depressions are then filled with stone chips not larger than two and one-half inches, and the whole left true and even and four inches below the line of finished grade and cross-section.

A good workman will average about twenty minutes in setting a square yard of this telford foundation, which may be formed of any kind of quarried rock which is most available: cobble-stones are not suitable.

The practice in 1901 in the states named is here shown:

Sizes of Stone for Telford Foundation, in Inches.

State.	Depth, as set on edge.		Width, as set.		Length, set across road.		Remarks
	Max.	Min.	Max.	Min.	Max.	Min.	
New Jersey.	8	8	4	..	10	..	Alternate end-stones double length.
Mass	6	5	10	4	15	6	Two inches gravel rolled on sub-grade as base.
Conn.........	8	8	10	6	13	8	Macadam covering formed in one layer.
New York ..	8	6	10	4	15	6	Used only on unstable ground as foundation for macadam.

Telford road in process of construction by
MASSACHUSETTS HIGHWAY COMMISSION.

The requirements for forming the four inches or six inches of broken stone roadway upon this telford foundation are the same as for regular macadam.

Of the mileage of broken-stone roads built by State aid during 1900, telford foundation was used for one-sixth in New Jersey, one-seventh in Connecticut, one thirty-eighth in Massachusetts and none in New York. During 1901, New Jersey used the same proportion as in 1900.

NEED OF BINDER WITH BROKEN STONE.

Macadam required that the layer of regular fragments should be spread on the earth roadbed, to be consolidated by the wheels of passing vehicles, without the aid of any fine material or of "binder" of any sort.

This requirement was impracticable and probably could not be enforced, and experience has shown that it is not desirable that it should be enforced.

Such fragments, loosely piled or spread, have about forty-six to forty-eight per cent of void spaces, and will pack by rolling to about three-fourths of their thickness when loose.

The consolidation of perfectly clean, regular, angular fragments of trap rock, free from screenings or binder of any sort, was thoroughly tried by Mr. Grant in Central park, New York city, in 1860. A piece of road covered with Macadam's ideal road metal, free from binder, was rolled for several days, until the fragments were worn and rounded, without firm consolidation being effected, and this experience has been recently repeated elsewhere.

Road material which can be packed without binder must be of a poor quality, which will supply itself with binder by readily grinding into dust and small pieces.

Telford's system differed radically in that he first covered the earth roadbed with a rough pavement of firmly set stones, and that the wearing layer of broken fragments varied in size, and that a binder of fine material was spread over the surface to help in its consolidation.

MODES OF USE OF BINDER.

This is one of the most important features of macadam road construction, and the different modes which produce successful results on State roads are therefore given in detail.

In England there are now various methods in use, but as a general thing Macadam's method of using perfectly clean fragments of hand-broken rock is not now followed. The commonest practice seems to be to use twenty-five per cent of binder called "hoggin," consisting of a mixture of loam, coarse sand and small gravel. This "hoggin" being worked into the layer of broken stone by flooding the roadway with water.

In France, where the greatest care is given to road construction and maintenance, twenty-five per cent of sand is generally used with the broken rock as a binder. This is washed to fill the voids between the fragments of rock, with a final addition of chalky dirt and water to fill the voids in the sand. See quotation on page 169.

In the United States, where little or no stone is now broken by hand, experience has satisfied most American engineers that the roads wear better and have less dust and fewer loose stones if binder is put upon the consolidated layer of crushed stone to fill the spaces which remain after rolling, and this binder is usually the stone dust and the small fragments from the crusher which pass through the circular holes, half an inch in diameter, of a revolving cylindrical screen. The use of binder is the same whether the construction is telford or macadam.

In New Jersey, after the lower course of broken stone has been rolled until compacted, trap rock screenings one-half inch to dust, free from loam or clay, are spread over the lower course in a uniform layer and the course is again rolled until the stones cease to sink or creep in front of the roller; water being applied in advance of the roller if required. The same treatment is given to the top course. This is then covered with a mixture in equal parts of three-fourths inch crushed trap and of half inch trap screenings, properly mixed and spread in sufficient thickness to make a smooth and uniform surface which is rolled until hard. Sandy loam is used with good results upon some New Jersey roads.

In Connecticut, after each of the two courses has been rolled until solid and fim, dry trap rock screenings not larger than one-half inch are scattered over the surface so as to fill all interstices and the roller is then run over the road to shake in the dust.

The sprinkler is then used to wash in the screenings and then more screenings are added, rolled dry and then sprinkled, and these processes are repeated for each course until all interstices are completely filled. When the top course has thus been made firm and smooth, it is then covered with one inch of screenings to form a wearing surface.

In Massachusetts, the lower course is thoroughly compacted by rolling, but no screenings or filler are spread or used upon it. After the top course has also been thoroughly compaced by rolling, screenings of the same kind of stone which forms the top course are laid on in just sufficient quantity to cover the stone and are then watered and rolled until the mud flushes to the surface. The screenings are not treated as a part of the wearing surface but are used simply to hold the larger stone in place, using as little as possible.

In New York, the screenings used as filler are usually limestone when the road-material is brought from a distance, but are often the product of the local crushed stone when local rock is fit for use; sometimes local rock and its screenings are used for the lower course only, but when possible they are used for the top also. In some cases when local granitic rocks are used, the screenings for the top course are caused to bind properly by mixing an equal amount of limestone screenings with granitic screenings. In other cases good results have been obtained by mixing an equal amount of clean sand with the granitic screenings. Trap and granite and quartzite screenings are limited to a maximum of one-half inch, but those of softer rocks are limited to three-quarter inch. After the first course of broken stone has been rolled until the stones do not creep or weave ahead of the roller, the dry screenings are spread uniformly to a depth of one-half inch and are then rolled dry and are swept with brooms of steel or rattan until the screenings disappear among the stones, when the process is repeated until no more will go in while dry: the surface is then wet with a sprinkler (unless the subgrade is of clay), using water freely until all voids are filled, leaving the surface of the stones free from screenings. See page 175.

The top course is then spread and rolled and treated in the same manner in sections of about 300 feet length, water being freely used and the rolling continued until a grout has been formed of the stone-dust and water and until a wave of this grout is pushed before the wheels of the roller. After this effect is produced, screenings are spread and rolled, leaving three-eighths of an inch depth for a wearing surface. After forty-eight hours, or when the surface has dried, the road is again rolled and sprinkled and then opened to traffic, being meantime sprinkled daily for thirty days.

QUALITY OF SCREENINGS.

Trap.—The best "binder" for the top course, all things considered, is probably a mixture of three parts of trap-rock dust and screenings, with two parts of smooth sand not too coarse. In addition to its toughness, trap-rock dust has the advantage as compared with limestone dust, of having a greater specific gravity, so that it does not blow readily. If this mixture fails to "bind," or if it "ravels" afterward, a different grade of sand may help it, or a small addition of one-fourth or less of cementitious limestone screenings, like that from Tompkins Cove, will certainly make it bind.

Limestone.—Some kinds of limestone screenings make a sticky paste, which is very bad, and it is important to select carefully and to study the effects closely. Cementitious limestone dust and screenings "bind" broken stone better than will any other material, and many experienced road-makers consider that limestone of some kind is necessary to make a good road; but the facts remain as detailed on pages 157, 158 that vast extents of perfect roads have been built and maintained without it, both in this country and abroad, during years past as well as recently.

Granite.—The screenings crushed from granitic rocks and from gneiss have in some cases been successfully used to bind the crushed rock from which they were screened. In other cases, during 1901, perfect results have been obtained from granite screenings which would not "bind" by mixing with them an equal quantity of carefully-chosen local sand.

Quantity of Screenings.—The actual quantity of screenings required to thus bind the crushed stone and to fill the voids, varies somewhat with the character of the rock and with the degree to which it is crushed and ground together by the roller: with trap rock, which is not crushed by rolling, the loose yardage of screenings needed to fill the voids will equal thirty-three per cent of the loose yardage of the crushed rock measured in the bin: with some gneiss, or with soft limestone, or with sandstone, the screenings may not exceed twenty-five per cent of the loose yardage of the crushed stone measured in the bin. A fair average with the various rocks will be thirty per cent, which will be ample if the screenings are not wasted.

MAXIMUM GRADES FOR MACADAM ROADS.

There is a wide difference between theory and practice in the matter of maximum grades on which broken-stone roads may be built and maintained. Grades of less than five feet per 100 feet are not only better for the traveling public, but can also be built and maintained at less cost, because it is more difficult to roll macadam on steeper grades, and because the fragments are loosened by horses toe-calks and are washed by rain-fall.

In the construction by state aid in the states already named, the roads are necessarily outside of corporate limits and are usually old highways on which the steeper grade can be reduced by cutting the tops of the hills and by filling the valleys, or in extreme cases by changing the line of the road and making a new location around a hill instead of going over its top. In this way, the maximum grade on state work in Massachusetts and in New York is nominally five feet per hundred because this is considered to be the most economical for the convenience of travel and for the cost of maintenance. In both these states, grades as steep as six and one-fourth feet per hundred are found necessary in some cases.

VANDENBURGH AVENUE, TROY, N. Y.

Surface of two inches of trap on base of four inches of limestone. Grade reduced from 14 ft. per 100 ft. to 6.75 ft. per 100 ft., 1901.

In New Jersey, among the roads built in 1900 are the following upon which the grades are steep:

NAME OF ROAD.	Construction.	Thickness, inches.	Width of macadam, ft.	Max. grade, ft. and tenths per 100 ft.
East Passaic avenue....	Telford	8	16	7.5
Budd's Lake road......	Macadam ..	6	10 to 16	7.5
Passaic ave. (E. bank Passaic river)........	Telford	10	20	8.86
Patterson and Hamburg Turnpike............	Macadam ..	4	16	9
Mendham-Bernardville..	Macadam ..	6	12	10.75

Upon city streets, however, it is often difficult to make any radical change in the grade, and always impossible to avoid hills by change of location, so that grades which are steeper than these are sometimes used, and with surprisingly good results.

The city of Newton, Massachusetts, comprises fifteen villages in an area of twenty square miles, containing some sixty miles of the finest macadam roads, which are built and maintained in perfect order by commissioner Chas. W. Ross, formerly member of the state highway commission. Among these finely kept roads are the following:

NAME.		Length of steep grade.	Grades in feet per 100 feet.
VILLAGE.	STREET.		
West Newton	Chestnut street	1000 feet	9 feet
West Newton	Mt. Vernon street ..	1000 feet	9 feet
Newtonville.......	Highland avenue...	1000 feet	10 feet
Newtonville.......	Otis street..........	1200 feet	10 feet
West Newton	Prospect street.....	700 feet	10 feet
West Newton	Putnam street......	600 feet	10 feet
Newton	Bellevue avenue....	1500 feet	9 feet
Newtonville......	Newtonville avenue.	1000 feet	12 feet

All streets having grades steeper than five feet per 100 have paved gutters three feet or more in width for which concrete is preferred to cobbles as being more durable, being free from weeds, and giving the best flow.

The city of Waltham, Mass., has fine macadam streets with the following described steep grades built since 1895:

NAME OF STREET.	Length of steep grade.	Width of macadam in ft.	Max. grade, in feet per 100 feet.
Main street	1000 feet	40 feet	7
Newton street	500 feet	20 feet	8
Plympton street	700 feet	20 feet	9
Bellevue street	400 feet	20 feet	12
Plympton street	400 feet	20 feet	13

These streets have paved gutters three and one-half feet wide and the cost of their maintenance after the first year is stated by superintendent R. A. Jones to be about one cent per square yard per year.

Clinton, Mass., has the following described macadam streets with steep grades, maintained by superintendent Loring B. Walker:

NAME OF STREET.	Length of steep grade.	Width of macadam in feet.	Max. grade, in feet per 100 feet.
Boylston street	6000 feet	18 feet	6
Chestnut street	1800 feet	14 feet	7
Sterling street	3000 feet	24 feet	8
Church street	3000 feet	24 feet	9
Main street	3000 feet	24 feet	10

These streets have paved gutters four feet wide.

Cambridge, Mass., has steep grades on Lancaster street, Humbolt street and Washington avenue, maintained by superintendent R. A. Brown. Medford has a steep grade on High street while there are also steep grades, kept in good condition, in Brookline, Chelsea, Malden, Winchester, Woburn and Somerville, Mass.

On Staten Island, now the Borough of Richmond of the city of New York, there were built from 1895 to 1901, by Henry P. Morrison, M. Am. Soc. C. E., 183 miles of macadam streets, which include some having steep grades which are described as follows: they are now in charge of Louis L. Tribus, M. Am. Soc. C. E.:

NAME.		Length of steep grade.	Width of macadam in feet.	Max. grade in feet per 100 feet.
VILLAGE.	STREET.			
Garretson's ..	Ocean terrace....	800 feet	16 feet	9
Garretson's ..	Prospect avenue..	500 feet	16 feet	10
Stapleton....	Orient avenue....	100 feet	16 feet	10
Stapleton....	Orient avenue....	100 feet	16 feet	16
Garretson's ..	Four Corners' road	500 feet	16 feet	11
Stapleton....	Trossack road....	730 feet	16 feet	12
Clifton......	Hillside avenue...	1600 feet	16 feet	12
Stapleton....	Occident avenue .	100 feet	16 feet	11
Stapleton....	Occident avenue .	100 feet	16 feet	13
Stapleton....	Occident avenue .	100 feet	16 feet	14
Stapleton....	Occident avenue .	100 feet	16 feet	16
Stapleton....	Louis street......	300 feet	16 feet	11
Stapleton....	Louis street......	200 feet	16 feet	20

These streets are formed of eight inches of crushed trap (except Trossack avenue which is six inches) all thoroughly rolled with four inches of crown, and all except three have paved gutters.

CONSTRUCTION OF A MACADAM ROAD.

The earth roadbed must first be drained, and in flat streets where the usual deep side-ditches are impossible, there must be shallow brick paved gutters to take the surface water at each side of the street and also porous tile drains, two feet below them, to collect the ground water and carry it to the sewers. See page 10. Curbs will usually be required for a city street.

SUBGRADE.

The subgrade, must then be cleared of all soft and loose material, preparatory to forming it on the best grades obtainable, with a regular crown or convexity of about one-half inch per foot for any grade up to five per cent and for widths up to sixteen feet, and of three-fourths inch per foot for steeper grades. (See page 36.) Old roadbeds usually have more or less hard and firm material beneath the objectionable dust and mud, and this firm substratum should be disturbed as little as possible by establishing the grade line high enough to avoid it.

A steam roller passing over an earth roadbed will disclose the existence of a surprising number of yielding places and soft spots which could never be found in any other way, but which can readily be filled, or excavated and refilled and re-rolled, until the earth is regular and equally hard throughout.

Instead of first forming the side-ditches and the crowned subgrade, as is usually done, it is sometimes better practice and easier for the roller to grade the roadbed flat in cross-section and at about two inches below the desired elevation of the center of the crowned subgrade; deferring the ditches until the last, unless their excavation is at once necessary to provide grading material or to take storm water.

On this flat roadbed, use the roller and admit traffic until the whole surface is so hard that the wheels of a loaded wagon leave no ruts. When ready to prepare for spreading stone, stake out the proposed macadam and drive twenty-four inch by one-half inch steel pins fifty feet apart along each edge and stretch a cord at the correct elevation of the proposed surface of the base course: then use square-end shovels and picks to cut down four inches along the cords, sloping the cut to nothing at three feet toward the center for a sixteen feet roadway, or more for a wider one: throw the excavated material into the center to form the crown and roll it till firm, making the center at the right elevation and forming the desired crown to receive the stone. The side ditches can be left to be dug and paved after the completion of the macadam roadway. Several experienced contractors who have doubtfully tried this method, have adopted it as their regular practice.

All precautions must be taken to secure the permanence and solidity and dryness of the subgrade, and it is an economy for the contractor during construction to get it as hard as described because this prevents the loss of costly crushed stone, and it is also an economy in future maintenance by prolonging the life of the roadway.

Broken stone roads have been "built" in cities by spreading six inches of good crushed trap upon the mud and dust of a soft subgrade with the result of total failure within two years.

Sand Subgrade.—A subgrade of sand which will not consolidate even when wet, may be fixed by covering with three inches of loam, or of shale or gravel, or with a thin layer of broken stone, either of which will probably consolidate under the roller after wetting. Peculiarly loose sand is sometimes found, into which one's arm can be thrust to the elbow, and this has been bound as above. This difficult condition is also well met in an article entitled "Economic Design of Streets and Pavements," by Halbert Powers Gillette, re-printed from the Engineering News, in the very complete 1901 report of the highway commissioner for New Jersey, Henry I. Budd, as follows:

> "Sand can be made quite as unyielding as gravel simply by filling the voids with fine dust or pulverized sand. No rolling is necessary. Water, if supplied in abundance, will puddle sand to which fine dust has been supplied, until the sand becomes hard and unyielding."

A telford base may be required as discussed on page 152. A layer, one and one-half inches thick, of three-quarter inch to one inch broken stone, coated with hot bitumen and rolled at once, will serve in an extreme case where simpler ways fail.

Clay Subgrade.—Subgrades of slippery clay showing increasing waves when rolled with a twelve ton to fifteen ton roller, have been consolidated, after subdraining with buried tiles, by covering the clay with a layer of freshly-cut straw and then rolling with a lighter roller, ten tons in weight. This has also been done by covering the clay with a single layer of quarter inch to half inch green brush, rolled into the moist clay and then covered with an inch of sand and again rolled.

Small areas or "pockets" of springy wet clay must be removed, or must be drained and then covered with a layer of gravel or coarse sand.

Settling a Clay Subgrade.—It is sometimes best, and has been done with good results, to rough-grade a clayey subgrade and to let it stand under traffic for some months, or better through a winter, before preparing it to receive the broken stone.

Sandy Loam Subgrade.—This is most difficult when the particles are very fine, so that the capillary attraction prevents sub-drains from taking the ground-water; in such case, this part of the road must be watched during the first wet season after completion, and if it shows signs of yielding under traffic, the layer of broken stone must be increased in thickness, as is discussed on page 177, in the quotation from W. E. McClintock, M. Am. Soc. C. E.

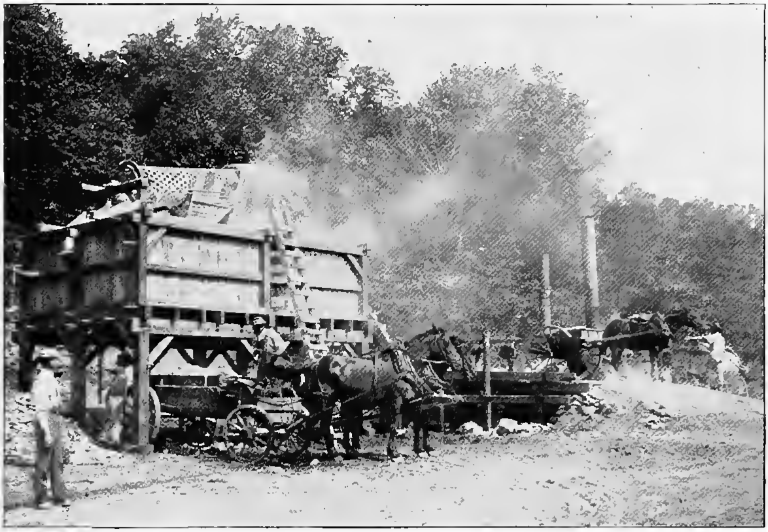
Various expedients must be tried until one is found, by which the subgrade will remain firm and smooth when the broken stone is spread and rolled upon it, so that the fragments shall not work down into the subgrade, nor the material of the subgrade work up among the fragments, under the action of the roller. The stone thus saved is worth more than the cost of this special work.

Remove Stones.—Stones or rocks lying within half a foot of the top of the subgrade, and which are larger than six inches, should be removed, lest they serve as anvils on which traffic will crush the road-metal.

QUALITY OF ROCK TO BE BROKEN.

The rock should be hard, tough, durable and uniform in character, fracturing with a toothed surface and showing a tendency to break into cubes rather than into flakes. This latter pecularity occurs with some rocks which would otherwise be good, and in one case was found to be the direct result of excessive use of dynamite in the quarry.

The rock should have a composition which cements when wet and rolled, and should come clean from the



Tailings larger than 3 inches to return to crusher. Wagon loading crushed stone from bin. Cart dumping rock from quarry onto platform over crusher.

Screens and bins for screenings and three sizes of stones. Crusher producing 135 cubic yds. crushed stone per day.

CRUSHING AND SCREENING ROCK.

quarry to the crusher. A softer rock may be crushed for the base course, and its screenings will usually form a good filler for it. (See page 161.)

CRUSHING.

The crusher should be placed where the rock will pass down from the ledge through the crusher and through the bins into the wagons, and then down-hill to the work. The crusher should be set to produce the largest size specified, and the whole product should then be screened through a series of three revolving screens or cylinders pierced with circular holes, set on a slope so that the material passes slowly as the screens revolve into separate bins for each size. Thin slabs and long pieces and the "tailings," should be re-crushed. Sixty cubic yards of solid rock in the ledge allowing for quarry waste will make about 100 cubic yards of loose rock which will produce about 125 to 135 cubic yards of the different sizes measured separately.

The following results were obtained in crushing hard flinty limestone weighing 168 pounds per solid cubic foot, or 2171 pounds per cubic yard of quarry fragments of one to two cubic foot each, of which a mass showed fifty-two per cent of voids and 100 cubic yards produced as follows:

Size of screened products.	Number of cubic yards.	Weight per cubic foot.	Per cent of voids.
2 inch to 1½ inch..	95	96 pounds	43
1½ inch to ⅝ inch..		91.5 pounds	45.5
⅝ inch to $\frac{3}{16}$ inch..	14	92 pounds	45.2
$\frac{3}{16}$ inch to dust inch .	19	93 pounds	44.6

One hundred and eighty cubic yards of quarry-rock were crushed in ten hours and the product was screened and put in bins and cars at a total cost for plant, fuel and wages of fourteen cents per cubic yard of product. The usual cost is twenty cents, and with a smaller crusher, thirty cents.

The screens should be selected to produce the required sizes, two and one-half inch circular holes giving what are known to dealers as "two inch" stone: one and one-fourth inch holes giving "one inch," used for the binder-coat of asphalt pavement: one inch holes giving "three-fourths inch:" one-half inch holes giving "screenings:" one-fourth inch holes giving "one-eighth inch dust."

Preparing subgrade.

Finishing subgrade.

Spreading and binding foundation stone.

RIVER-ROAD NEAR BUFFALO, NEW YORK.

Surface of two inches of trap rock on base of four inches of limestone.
Built by State Engineer E. A. Bond, M. Am. Soc. C. E., in 1900.

The required sizes vary as indicated in the following table showing the practice during 1901–2 in the States named:

SIZES OF BROKEN STONE AND THICKNESS OF COURSES, IN INCHES.

STATE.	LOWER COURSE OF MACADAM.			UPPER COURSE OF MACADAM.			SURFACE.			Size not used.
	Size of Fragments.		Thickness after rolling.	Size of Fragments.		Thickness after rolling.	Size of Fragments.		Thickness after rolling.	
	Min.	Max.		Min.	Max.		Min.	Max.		
New Jersey....	2	3	4	1	2	2	dust	¾	smooth surface	¾ to 1
Massachusetts.	1¼	2½	4	½	1¼	2	dust	½	smooth surface	none
Connecticut ...	¾	2	4	1	1½	2	dust	½	1	½ to ¾
New York	1½	3	4	1	2	2	dust	½	⅜	none. *

* One-half inch to one inch spread on subgrade as one-third of the base course.

FORMATION OF LOWER COURSE.

The thickness of the layer of loose stone spread for this course should be gauged by five and one-half inch cubes of wood placed upon the subgrade, including a bottom layer not more than one and one-half inches thick of that part of the crusher product not otherwise required.

The stone should be uniformly spread to this depth, beginning furthest from the source of supply in order to avoid driving over the loose stone, and using spreader-wagons to uniformly distribute it. If ordinary wagons are used, the stone should be shoveled from the wagons or from the roadside. If dumped in large piles upon the subgrade of the road, the position of each pile will be made evident after the road is finished. When several hundred feet of roadway have been covered, the rolling should begin along each edge, lapping on to the earth shoulder and rolling each side several times until the fragments do not creep or weave before the roller when they will be compressed to four inches. No screenings or water should be put on till after this: the use of dry screenings is described on page 159.

When the lower course is properly filled and bound it will be so firm and solid that loaded wagons can pass over it without leaving any mark, but the surface of the stone should be free from screenings.

FORMATION OF TOP COURSE.

The top course, perferably of trap, is then spread in the same manner, using two and three-fourths inch gauge-blocks and rolling the loose stone to two inches, and until the fragments do not creep and weave, before spreading the dry screenings as described on page 160. Sometimes it is required that the rolling of the top course shall continue until the material is packed so firmly that an inch cube of trap laid upon the finished surface shall crush under the roller without sinking into the road surface.

A properly made macadam pavement resembles a mass of concrete, and in several cases has proved self-supporting when the earth beneath it has been washed out by floods.

Smooth surface of roadway. Cave made by washout.

MACADAM ROADWAY, SIX INCHES THICK, OVERHANGING A WASHOUT.

THICKNESS OF BROKEN STONE FOR MACADAM ROADWAYS.

Careful studies have been made by W. E. McClintock, M. Am. Soc. C. E., as to the bearing power of various soils in order to adjust the thickness of the layer of broken stone to suit the soil and the traffic. His valuable conclusions are given in the 1901 report of the Massachusetts highway commission, of which he is Chairman, as follows:

"The Commission has estimated that non-porous soils, drained of ground-water, at their worst will support a load of about four pounds per square inch; and having in mind these figures, the thickness of the broken stone has been adjusted to the traffic.

"On a road built of fragments of broken stone, the downward pressure takes a line at an angle of forty-five degrees from the horizontal, and is distributed over an area equal to the square of twice the depth of the broken stone. If a division of the load in pounds, at any one point, by the square of twice the depth of the stone in inches, gives a quotient of four or less, then will the road foundation be safe at all seasons of the year. On sand or gravel the pressure may safely be placed at twenty pounds per square inch.

"Acting on this theory, the thickness of stone varies from four inches to sixteen inches, the lesser thickness being placed over good gravel or sand, the greater over heavy clay, and varying thicknesses on other soils. In cases where the surfacing of broken stone exceeds six inches in thickness, the excess in the base may be broken stone, stony gravel or ledge stone; the material used for the excess depending entirely upon the cost, either being equally effective."

CROWN OR SLOPE OF MACADAM SURFACE.

The convexity or crown of the roadway is usually made one-half inch to three-fourth inch per foot each way from the center-line for widths up to sixteen feet and one-half inch per foot for wider city streets. (See page 36).

The curve must be regular so that no water can stand upon the surface and must be continued uniformly over the wings to the ditches or gutters at the sides so that water will run off freely.

The roadway may have a plane surface, sloping wholly to one side, with good results. This construction is sometimes desirable when a street-car track occupies one side of the roadway and where it is necessary to drain the surface to one side: or when car-tracks occupy the center of the roadway and the macadam on each side must drain wholly to the ditch on that side. A nearly flat city street with forty feet width of macadam sloping regularly one-half inch per foot from one side to the other gave no trouble and was found in perfect order after several years use.

COST.

The cost of broken-stone roads varies with the local conditions and the supply of stone: the following approximate figures are for six-inch macadam complete, not including curbs or grading or drainage:

With local stone available, suitable for both base and top and filler, forty-five to fifty cents per square yard.

With local stone available for base only, top and filler coming from a distance, sixty to sixty-five cents per square yard.

With no good local stone, all coming from a distance, seventy to seventy-five cents per square yard.

For resurfacing roads, for which local stone is available as in Massachusetts, the average cost is ten cents per square yard for each inch in thickness.

THINGS TO BE AVOIDED.

The work should be so planned, and the traffic so diverted that there will be the least possible passing of wheels over the loose stone which have been spread to form the base course, or the top course, of a macadam roadway. The stones should be at once rolled, and should be bound together as soon as possible, in order to preserve the angles and the roughly fractured surfaces which would be rounded and worn smooth by traffic.

No screenings or sand, or earth from the subgrade, or "filler" or binder of any kind, should be allowed upon or among the regular fragments of loose stone until they shall have been thus rolled and consolidated. It will be difficult, if not impossible, to properly bind the stones if any "filler" gets between the fragments while they are loose.

Excessive rolling will injure the road, especially if there has been too much wetting, or if the stone is either soft or brittle. Experience is the only safe guide.

MAINTENANCE.

Broken-stone roads require constant care beginning as soon as they are opened to traffic. The cost is less for continuous attention than for deferred repairs.

The system of roads which was built early in this century all over England, required then, and still continues to require, the constant attention of an army of resident workmen living along the line of the roads and making never-ceasing repair of ruts and breaks as soon as they occur. Little piles of broken stone, or of stone to be broken, were and are never-absent evidences of constant care, and steam road rollers are often met when driving through the country. Such care is necessary and costly.

In London and in Paris broken-stone roads are the roads of luxury; some of the finest streets having macadamized central driveways, bordered on each side by thirteen feet of sheet-asphalt.

In Paris the annual cost of maintenance of suburban macadamized streets having light traffic is about one-third the original cost of building them. In some cases of extra heavy city traffic, the annual care costs one-third more than the original building; that is, the roadway fourteen inches thick has to be practically renewed every nine months. In such cases macadam is more costly than asphalt or wood blocks, which are therefore replacing it.

AVENUE du BOIS de BOULOGNE, PARIS.

Broken-stone roadway.

The rocks available and used for broken-stone roads in Paris are inferior to those used in and about New York. Edward P. North, M. Am. Soc. C. E., in his standard book, "Construction and Maintenance of Roads," states that of the Paris broken-stone roads, "sixty-seven per cent are made of *meuliere*, twenty-three per cent of porphyry and ten per cent of water-worn flint pebbles." *Meuliere* is a quartzite in which coarse grains of quartz are united by a peculiarly strong silicious cement. Neither the *meuliere*, the porphyry nor the flint is equal in durability to diabase trap.

The good condition of the Paris broken-stone roads, in spite of their indifferent materials, is the result of the perfect system of care which the French have learned to give to all their roads. One of the important avenues thus paved is the well-known driveway through the Bois de Boulogne.

In any case, eternal vigilance and a continuing supply of money are the price of a good system of macadam city roads.

Raveling.—Loosening of the surface-stone, or "raveling" is the most common defect, and this is checked and prevented by covering the traveled surface with half an inch of coarse sand or of trap-rock or other screenings, and by renewing this whenever it is displaced by traffic, by storm-wash or by wind. This layer prevents the toe-calks of horses from loosening the fragments of stone, and retards evaporation from the binder in which the fragments are embedded.

When the surface shows any loose fragments, these should be promptly restored to place if possible, or removed to one side, and the road should at once be thoroughly wetted, sanded and rolled.

Rolling.—Rolling is of special importance in the spring, as soon as the frost is gone and before the roadway becomes hard and rigid; or during a soaking rainfall while the road is somewhat plastic: the edges being rolled before the center, to restore and preserve the crown. This treatment will go far to keep the road in good condition for the rest of the year, especially if the traveled way is then covered with half an inch of sand or of screenings; never with clay, ashes or loam, unless fully mixed with three to four times their bulk of coarse, sharp sand.

Ruts.—When short ruts appear, as they sometimes will in the best of roads, especially during the first spring, the top layer of stone—usually two inches thick—should be taken out for a width a few inches more than the rut and for its full length. This will make a regular hole, which is slightly deeper in the middle than at the sides, and in which the fragments of stone should be replaced with a few additional ones of the same sizes and kind: the larger fragments being placed in the deeper center and the smaller ones toward the edges.

The loose fragments must then be rammed with a paving rammer and packed and consolidated until level with the adjoining old surface. Screenings or sand must then be added and brushed to fill the voids, with a final free sprinkling to aid the binding and last ramming until the patch appears as firm as the rest of the road and the surface has been perfectly restored. A small rut can be thus repaired by one man in a few minutes so that the place cannot be found the next day. Special care is necessary that the patch is made no higher than the adjoining surface, as an elevation of even half an inch may cause ruts to form around the patch. When long ruts appear, as they sometimes do in the spring before the road has been rolled, put picks in one roller-wheel and run it along the rut, loosening the surface, which then level into the rut and then wet and roll smooth.

Sometimes a rut consists of a slight depression between two slight ridges, and this condition can be easily corrected when rain-soaked by rolling down the ridges with the wheels of a broad-tired wagon in which a heavy load of stone is piled over the rear axle.

Ruts and hollows are best found and repaired during rainy weather.

Stones of a smaller size than the original top layer, or of a different kind of rock, should never be used for repairs, as the small fragments crush more readily than larger ones, and different kinds must wear unequally. It is not well for instance, to repair a trap rock road with patches of limestone, or the reverse.

The common practice of spreading and leaving two inches or more of loose "three-quarter inch stone" in the ruts and upon the surface of a worn macadam road, is wasteful of material and needlessly annoying to traffic, which should never be compelled or allowed to pass over loose broken stone. It costs less to spread a thin layer of larger fragments as described, and to at once pack it by using a steam roller.

Cleaning.—Mud must be scraped from the surface of a broken-stone roadway whenever it becomes deep enough to show tracks and to hold water. If mud is allowed to accumulate to a general thickness of one to two inches, and to remain, it will work down between the fragments of stone and eventually will destroy their bond. When this condition has been reached, resurfacing the road will mean re-building it at a greater cost than to have kept it clean.

Shoulders and Ditches —These must be kept in regular form, and the washouts filled, and the ditches cleared of sediment and dead leaves, and freed from growing weeds and grasses.

Cost.—Definite figures for this work on city streets are not easily kept separately, but the accounts of the expenses of thus maintaining rural broken-stone roads have been closely kept by the Massachusetts highway commission for several years and are given during 1901 for 166 roads with a total length of 334 miles.

Six of these roads, with a total length of seven miles, were evidently extreme cases and are not here included.

The remaining 160 roads, 327 miles long, ranged in cost of maintenance from about $4 per mile to about $300 per mile and averaged $70 per mile. The macadam surface of these roads is usually fifteen feet wide, being 8800 square yards per mile, and this at $70 equals eight-tenths per cent per square yard per year for maintenance.

RE-SURFACING.

A trap-rock road will ordinarily endure for several years without re-surfacing, but a limestone road will need it much sooner, because it wears faster and blows away more readily.

Whenever the surface of any broken-stone road becomes worn and irregular and the lower stones are exposed in spots, it needs re-surfacing. The street should be treated in sections 300 or 400 feet long, or as much as the force can begin and finish each day.

The steam-roller with picks in the wheels should be run over half of this section to loosen the top layer. If mud is found to be mixed with the fragments of stone in the road, rakes and potato-forks must be used to separate and save the stones, which can be used again with the addition of enough new stone of the same size and kind (usually trap rock) to restore the original thickness. If the road has been kept properly free from mud, it will only be necessary to add to the loosened top a single layer of one-inch to two-inch fragments, and to roll them into the loosened top layer, until all is solid and firm, binding with sand or with screenings, and wetting and rolling until a wave of "grout" goes before the roller, from which the picks have of course been removed. The operations can then be repeated on the other half, and the section opened to traffic the next day.

Cost.—This re-surfacing will require about 300 cubic yards of loose stone and about fifty cubic yards of screenings per mile of fifteen-foot roadway, the cost of which will vary with the freight charges. In Massachusetts, where there are no long hauls by railroad, the cost is $700 to $880 per mile, or eight cents to ten cents per square yard of surface for each inch of finished thickness of the broken stone.

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